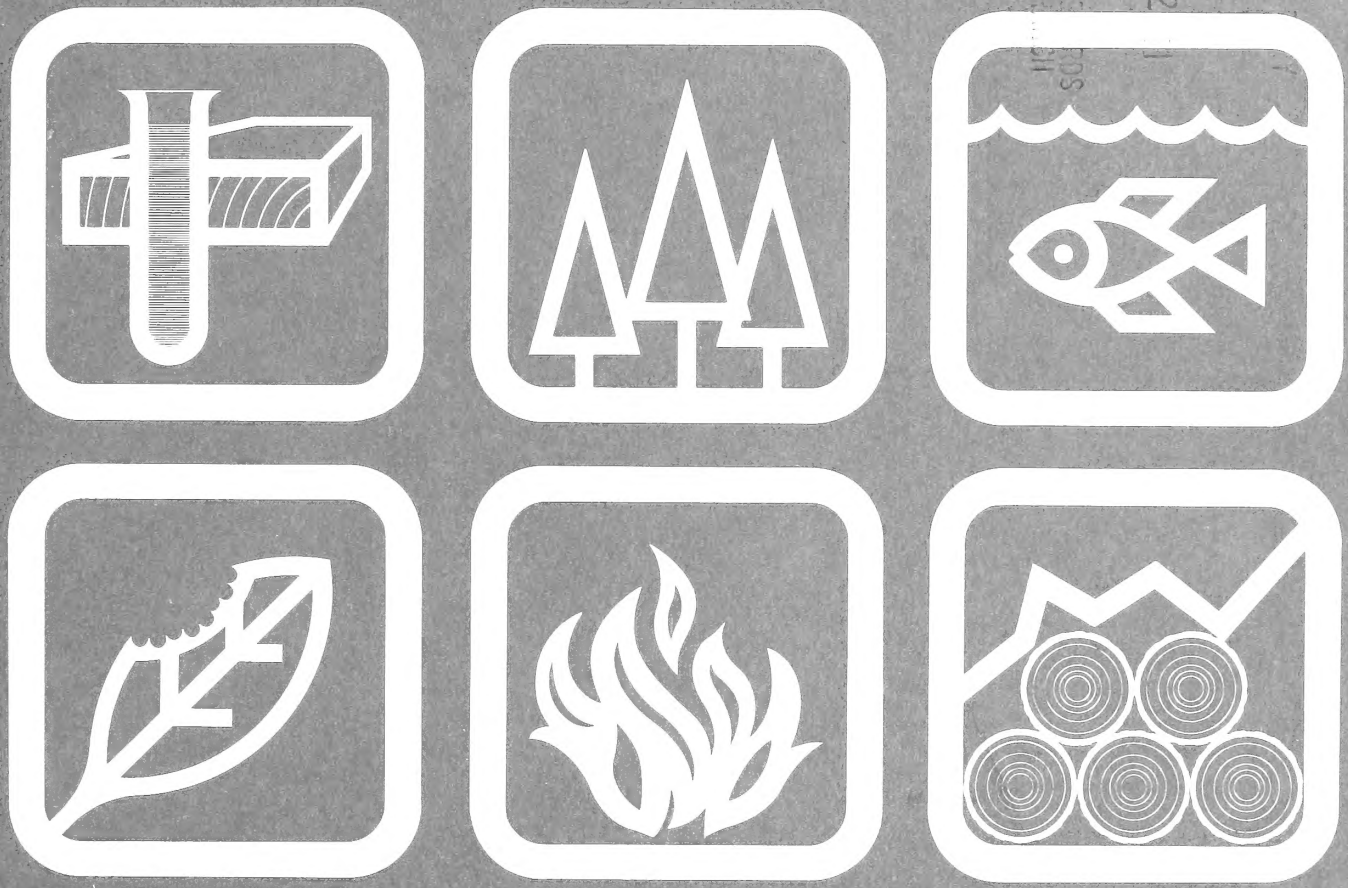
United States
Department of
Agriculture

**Forest
Service**

General
Technical
Report
WO-53

Protecting and Enhancing America's Forests and Rangelands

1986 Research Accomplishments



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December 1987

Foreword

Forest Service scientists are working cooperatively with specialists from universities and other Federal and State agencies on a wide variety of topics, to improve our ability to manage the Nation's forests and rangelands. This year's Research Accomplishments Report highlights over 80 major efforts, including both individual studies that came to fruition during 1986 and long-term, multi-Station projects. The report ends with a 2,600-item bibliography that lists all the publications about Agency-funded research released since late 1985.

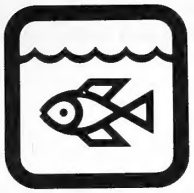
Forest Service research falls into six categories: Environment, Insects and Disease, Fire and Atmospheric Sciences, Timber Management, Resource Economics, and Products and Harvesting. Both the research highlights and the list of research-related publications are divided along these subject matter lines.

We are especially proud of our research on acid deposition, wildlife habitat, threatened and endangered species, and biotechnology--areas that should receive even greater emphasis in the coming decade. Our people continue to make applications-oriented discoveries, such as how to use a lignin-degrading enzyme to break down pollutants without chemical intervention and how to turn forest wastes and low-value trees into panel products. And they work on basic problems, too, such as how to improve streamflow by converting chapparal to grasses, how to reduce sediment pollution after harvesting timber, and how to lessen stand susceptibility to major insect pests like southern pine beetle or gypsy moth. We are working to improve growth and yield for the Nation's timber producers (including our own national forests) and to enhance the quality of our wildland areas for the benefit of all citizens. We study how to design bike trails to please city dwellers and suggest where to plant tress for maximum energy savings around houses. And since wood is our biggest product, we help professionals and laypersons preserve it with a comprehensive publication on exterior finishes.

Our economics people have forecast for the coming century a scenario of increasing population and corresponding increases in the demand for all the natural resources the Forest Service manages--timber, recreation, wildlife, water, minerals, range. Forest Service research aims to protect these assets and enhance them by developing improved management techniques for the benefit of all our citizens.

F. DALE ROBERTSON
Chief

Janet [Searcy] Wintermute, of the office of the Deputy Chief for Research in Washington, DC, edited and coordinated production of this report.



Environment

Sediment and Forestry Practices in the South

Sediment is the primary pollutant from southern forest lands. The Forest Service reviewed the results of small catchment studies conducted on diverse soils and topography across the hilly Piedmont and Coastal Plain, comparing them with 189 years of records. Data revealed a narrow range of average annual sediment concentrations for undisturbed forests of southern pine. The undisturbed pine in the Coastal Plain wetlands and the interior highlands produced less sediment. The average concentrations for these physiographic areas can be used as standards from which to measure changes due to forestry practices. It should not be necessary to monitor pretreatment levels.

Increased sediment concentrations following prescribed burning and harvesting were slight and short lived. Concentrations following sequences of treatments that included intensive mechanical site preparation varied considerably in the Piedmont and Coastal Plain. In some cases, they approached those from agricultural lands during the first year. Concentrations were highest in hilly terrain with unstable channels. Sediment production decreased more than one-half during the second year and more than two-thirds during the third year. Choosing mechanical methods that provide onsite storage for rainfall and sediment in these areas reduces sediment production risks. And, where channels are erosive, minimizing increases in storm flow volumes can protect water quality downstream from the disturbed site.

The data suggest that the mean values for undisturbed forests, and for disturbances other than intensive mechanical site preparation in the Piedmont-Coastal Plain, can serve as the state-of-the-art. That is, the variations among studies are less than the error of estimates derived from the costly application of available models. Acceptance of this premise together with application of Best Management Practices can result in very large savings for all sectors of southern forest management activities and can simplify regulatory functions designed to protect water quality.

Erosion and sediment production in southern California have been a major problem for nearly a century. Engineering and maintaining structures to trap or control distribution of this sediment is expensive, and disposal of sediment trapped by these structures is a problem. It seems apparent that it would be cheaper and easier to keep as much of this sediment as possible on the hillslopes where it originated.

When fires destroy protective vegetation, sediment-producing events occur more often and do more damage. Rain splash, overland sheet flow, and rill formation by concentrated flow are traditionally seen as major causes of sedimentation. Researchers at the Pacific Southwest Station have found that dry ravel (dry unconsolidated flow of particles on steep slopes) and small landslides can be more important than overland flow water erosion on freshly burned slopes. This erosion can be as much as 100 times greater than that from similar unburned areas. Postfire storms can further increase sediment production because of overland flow erosion. Canyon bottoms can store eroded sediment under favorable conditions and may provide opportunities for managing sediment production.

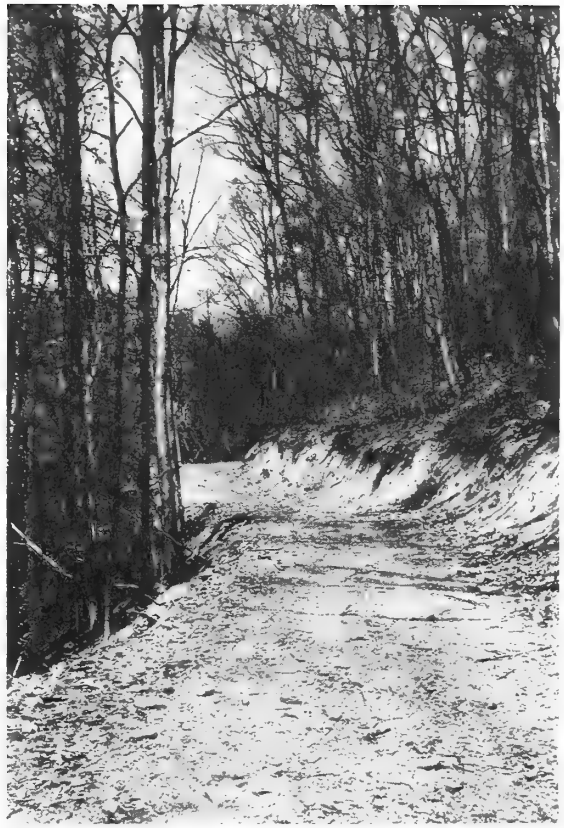
Seeding ryegrass (a fast-growing, introduced species) to stabilize surface soils after fire should theoretically help control sediment. But variability in precipitation patterns and site conditions can complicate the problem. Continuing research is testing the effects of seeding burned slopes and the long-term consequences of introducing an aggressive exotic species in chaparral environments.

Access roads are an essential feature of forest management. But they can contribute significantly to environmental degradation if poorly designed and carelessly constructed. Forest Service scientists at several locations throughout the United States have been working for several years to develop road designs and construction techniques that are environmentally sound and economical. Several recent developments are particularly significant.

A filter strip is a buffer zone, between a road and a stream or lake, that catches sediment that might otherwise reach the water. In North Carolina, we have been studying the utility of filter strips adjacent to roads. Narrow filter strips effectively control sediment. Outsloped roads with broad-base dips and obstructions such as brush barriers, and grass-covered road fills all contribute to decreased sediment travel.

Depth of surfacing material on minimum-standard roads has been studied in West Virginia. Soil losses from these roads, even without gravel, are not greater than that reported from higher standard roads in other parts of the Nation. Soil losses decrease and utility is improved when at least 3 inches of clean limestone gravel surfacing is used.

In Idaho, scientists have studied the effects of road design standards on erosion during construction. Road design has little effect: erosion depends more on the stage of construction when a storm occurs. Results emphasize the need for erosion control during construction. Coffer dams above culvert installation sites and pumping around the site during construction reduce stream sedimentation.



Low-cost, low-maintenance forest roads can be designed and built with features that protect water resources from unnecessary siltation.

Most of us know that snow has always provided more than a soft landing place for an awkward skier. For example, water from snow plays a key role in the vitality of this Nation, particularly in the West, where vast expanses of otherwise uninhabitable land are made pleasant by the slow release of water from snowpacks in the surrounding mountains. We also know that snowmelt water can be a problem. Its quantity, quality, and timing determine whether it will be available for productive use or become a liability. Through Forest Service research, we are learning how human activities can affect these critical properties.

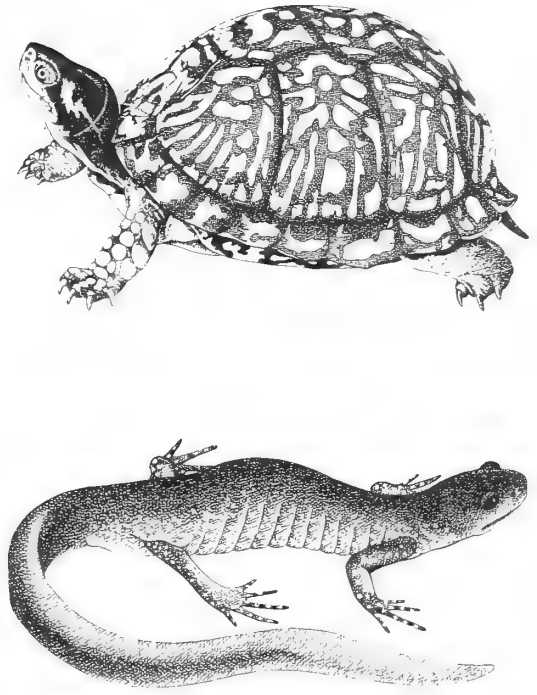
Pollutants contaminating the air also accumulate in winter snowfalls. Research in remote locations like the central Sierra Nevada in California helps us begin to understand the effects of pollutants on snowmelt quality. Recent research has demonstrated that snowmelt water is no more acid than rainfall, and the greatest acidity occurs when rain falls on the snowpack. In contrast, snowmelt caused by high air temperatures can produce alkaline pulses. This evidence suggests there may be some redistribution of snowpack pollutants before snowmelt begins in the spring.

Recent research indicates that clearcut logging in western Oregon forests alters snow accumulation and melting enough to increase the size of peak flows during rain-on-snow events. Higher peak flows indicate a higher rate of water delivery to soils. This can increase the potential for both hillslope and channel erosion.
Increased streamflow is not necessarily undesirable. Research in Wyoming has demonstrated that blowing snow trapped by snow fences can increase streamflow. A snow fence one-half mile long and 12 feet high, built on a shrub-covered watershed, more than doubled streamflow. About 85 percent of the snow trapped by the fence was measured as streamflow, without appreciably increasing peak flow rates. This first documentation of actual streamflow increases suggests that fencing windswept lands is an economical way to augment water supplies.

"New England Wildlife: Habitat, Natural History, and Distribution

New England's forests provide a diversity of habitats supporting a rich assortment of wildlife species. A new book by scientists of the Northeastern Forest Experiment Station presents the most comprehensive treatment of this resource that has ever been compiled. Nearly 500 pages of text present detailed life history accounts, range maps, and key habitat requirements for 335 New England wildlife species (26 amphibians, 30 reptiles, 220 birds, and 59 mammals). Preferred and suitable seasonal habitats of each species are shown for nine major forest-cover types by timber-size class and for 27 terrestrial and aquatic nonforest habitats.

This publication addresses the needs of land managers for a definitive reference that presents wildlife habitats in terms of managed New England forests. Public land managers must consider wildlife in forest management. Also, in New England, private woodland owners are frequently more interested in wildlife than in timber management. They need to know about the value of forest management in enhancing overall wildlife diversity. Both public managers and private landowners will benefit from this book.



The eastern box turtle and the blue-spotted salamander, two species featured in "The Natural History of New England Wildlife."

Bald eagles nest in limited numbers along major rivers in central Arizona, and several hundred from other parts of the country winter on national forest timberlands of Arizona and New Mexico. Significantly, the status of this endangered species is particularly precarious in the Southwest. The small breeding population, unique in its use of cliffs and desert habitat for nesting, is on the periphery of the species' range and relatively isolated from other breeding populations. Also, improper timbering operations can negatively affect habitat for wintering eagles.

Research by scientists of the Rocky Mountain Station is providing

Bald eagles in the Southwest do well in mild winters (characterized by high waterfowl populations) and in fairly severe winters (characterized by high populations of mammal prey), but their numbers decrease sharply when winters are so cold that prey availability drops off drastically.

resource managers with information needed to protect, enhance, and manage critical bald eagle habitat through development of habitat models, management guidelines, and manipulative techniques. A first-generation model, for example, has shown amount of cliff, degree of river curvature, miles of permanent side drainages, and extent of riparian vegetation to be important variables that discriminate nesting habitat. Another dimension of this research has examined the sensitivity of nesting eagles to human disturbance.

Investigations of wintering populations have shown that these migrants from more northern climates prefer to live at higher elevations because severe winter weather there concentrates available prey much more than in the warmer deserts below. Increasingly severe weather during winter provides a relatively constant abundance of prey, with waterfowl commonly used early in the season (before lakes freeze over) and big game carrion and small mammals used more heavily later in the winter. Bald eagles in the Southwest--unlike those that use other wintering areas--roost alone or in small groups and change their roosting areas opportunistically in response to changing prey abundance and weather conditions.

Some wildlife species depend on or reach their highest populations in forests that are older than the ideal age for economic harvest for wood products. We call such forests "old growth." Research being conducted by the Southeastern, Southern, Intermountain, Rocky Mountain, Pacific Northwest, and Pacific Southwest Stations seeks to learn how to integrate habitat management for the wildlife species that need old growth with management of younger and more vigorous forests for timber and fiber production.

One line of research, for example, focuses on habitat requirements of those 85 species of North American birds and 49 species of mammals that use tree cavities. Related research examines ways of producing suitable habitat for cavity-excavating species where it is lacking, such as by injecting selected trees with a wood-decay fungus.

Additional research studies wildlife species that require other components of old-growth habitat. In southeastern Alaska, for example, Sitka black-tailed deer are closely associated with old-growth Sitka spruce-western hemlock forests. Research focuses on understanding the nature of this relationship and development of habitat models to predict the response of deer to changes in habitat.

The most comprehensive old-growth habitat research ever undertaken by the Forest Service is in progress in Washington, Oregon, and California, where stands of Douglas-fir often exceed 250 years of age. The northern spotted owl has been found to be associated with these forests and could be irreparably harmed by indiscriminate and large-scale cutting of old-growth stands. Preliminary results of research in progress suggest that other species may also be associated with these forests. The aim of our Douglas-fir old-growth research is to provide new information needed to ensure that populations of these species are maintained in concert with other essential forest uses.

Studies are identifying characteristics of habitats across moisture gradients and stand age so that a comprehensive Douglas-fir old-growth classification system can be developed. Large-scale studies of wildlife distribution and abundance are providing information about species associated with old growth, including major prey of the northern spotted owl. The Forest Service is initiating more detailed investigation of individual species and groups of species to learn their specific needs and the nature of their association with old-growth habitat so that management guides can be developed.

Among the latter studies, special emphasis is being given to the northern spotted owl. Current spotted owl research is focusing on study of movements, habitat use, breeding activity and success, juvenile dispersal, prey ecology, effectiveness of management guides, and potential competition with barred owls.

Examples of 1986 old-growth research accomplishments follow:

- The proceedings of a symposium on the ecology and management of the spotted owl in the Pacific Northwest has been published. The symposium, cosponsored with

the Cooper Ornithological Society and Humboldt State University, brought together the current state of the knowledge on spotted owl management, the most recent results of research, and the latest thoughts on application of population theory to spotted owl management.

- In California, certain species are sensitive to size of Douglas-fir old-growth stands. They are found only in old-growth stands greater than 25 acres.

- Tests of a spotted owl habitat model in California have identified variables important to refining such models.

- Investigations of a multispecies model for the Douglas-fir type in California showed that the model adequately predicted species occurrence but not abundance.

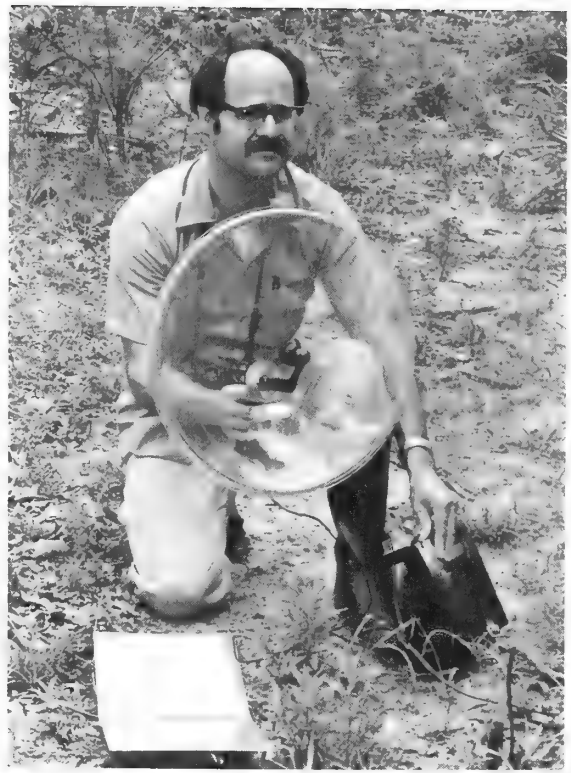
- In eastern Oregon, large-diameter standing dead trees and downed logs, found in old-growth forests, are essential habitat for the pileated woodpecker.

- In the Southeast, research on the endangered red-cockaded woodpecker has quantified the sex ratio of young birds, which is an essential link in the knowledge base needed to estimate population viability. Also, finding more males than females is the first empirical evidence of a biased sex ratio in cooperative breeding birds--a subject of great theoretical significance to evolutionary scientists.

The northern spotted owl--an endangered species native to the old-growth Douglas-fir stands of the Pacific Northwest--is the subject of several Forest Service studies. We are trying to determine its habitat requirements so that adequate acreages of old-growth can be set aside to ensure that spotted owl numbers will not be further reduced.

Forest Service research is seeking innovative ways to assess habitat and monitor changes in habitat quality. Investigators at the Southern Forest Experiment Station have found evidence that a bird's song may tell something about the quality of its habitat. Cardinals with less complex songs hold better quality territories with more understory foliage and insect food, and raise more young than cardinals with more complex songs. Cardinals in three different habitats (sapling, pole, and sawtimber stands) used songs with different characteristics. Young cardinals may use complex songs when first establishing a territory, but less complex songs in subsequent years, when more effort is expended in nest defense and care of young.

Experts can only speculate on the meaning of these findings to avian behavior and ecology. Nevertheless, the research has opened up a new arena of study for the science of ornithology and potentially could provide a means of assessing changes in habitat induced by forest management.



Recording the songs of northern cardinals has shown that they sing differently depending on their numerical concentrations in a given area. In the long run, increased understanding of song patterns and frequency could enable scientists to verify the success of habitat manipulations with simple recording equipment.

Within the contiguous United States, rangelands include approximately 650 million acres of land on which native vegetation is predominantly grasses, herbs, or shrubs. These include natural grasslands, savannahs, shrublands, most deserts, and wet meadows. Also, additional millions of acres of associated woodlands supporting an understory or periodic cover of shrubby vegetation could be considered range. Among their many uses, rangelands provide essential habitat for hundreds of wildlife and fish species, including some that are threatened or endangered and many that are important for their economic and recreational values.

Forest Service research seeks to define habitat requirements of rangeland wildlife and fish species, clarify the relationship between livestock grazing and fish and wildlife, and develop and test new plants and methods for rehabilitation and management of rangeland habitats. Research in this program area is being conducted by the Pacific Northwest, Pacific Southwest, Intermountain, Rocky Mountain, and Southern Stations.

Developments completed during 1986 include the following:

- A new research unit established in Boise, ID, will study riparian-stream ecology and management. Work will focus on habitat relationships among riparian wildlife species, development of a comprehensive land-aquatic classification system, development of riparian rehabilitation methods, and testing of grazing strategies for compatability with wildlife and fish habitat-management objectives.

- A major research endeavor was initiated in eastern Oregon to provide a scientific basis for forage and habitat allocation among cattle, deer, and elk so that the outcome of management alternatives can be predicted.

- A new book entitled "Wildlife Habitats in Managed Rangelands" was completed in cooperation with the Bureau of Land Management. The purposes of this book are (1) to develop a common understanding of wildlife habitats of managed rangelands, (2) to provide a system for predicting the impacts of range-management practices on wildlife, and (3) to show how the system can be applied to a specific area--in this case, the Great Basin of southeastern Oregon.

- Research in the Southwest is addressing the relationship of land use to stream habitat. Recent investigations have revealed that desert streams historically received a substantial but sporatic input of downed large logs and trees, which are important in forming fish habitat. This material is not available today because of interception by reservoirs and because improper streambank management practices have prevented tree replacement.

- Current studies in the northern high High Plains seek to define and describe plant communities and associated wildlife. Investigations have identified key ecological relationships of bird communities among several prairie woodland types.

Some 3,000 species of vertebrate animals inhabit national forest lands, and many of them are found in managed forest stands--those areas that have been previously cut or otherwise silviculturally treated and that will be harvested before old age and decadence set in. To provide for wildlife, forest managers must have knowledge of all wildlife within their planning units and be able to anticipate the response of individual wildlife species and wildlife communities (groups of species) to planned changes in vegetation composition and structure.

A major segment of the Forest Service's wildlife research program is directed toward meeting this goal for the managed forest. Research focuses on discovery of habitat requirements of individual species and development of models to predict changes in distribution and abundance of species with changes in habitat. On a broader scale, other investigations are examining what groups of species, or wildlife communities, live in different habitats and how these communities change over time with forest harvesting, stand treatment, and stand development. Effort is also being made to devise cost-effective methods to measure, or monitor, wildlife response resulting from management activities.

Here are some examples of research completed in 1986:

- Research in Missouri by the North Central Station has developed and tested habitat capability models for the ovenbird and wood thrush that will provide a useful tool in predicting response of these species to forest-management activities.

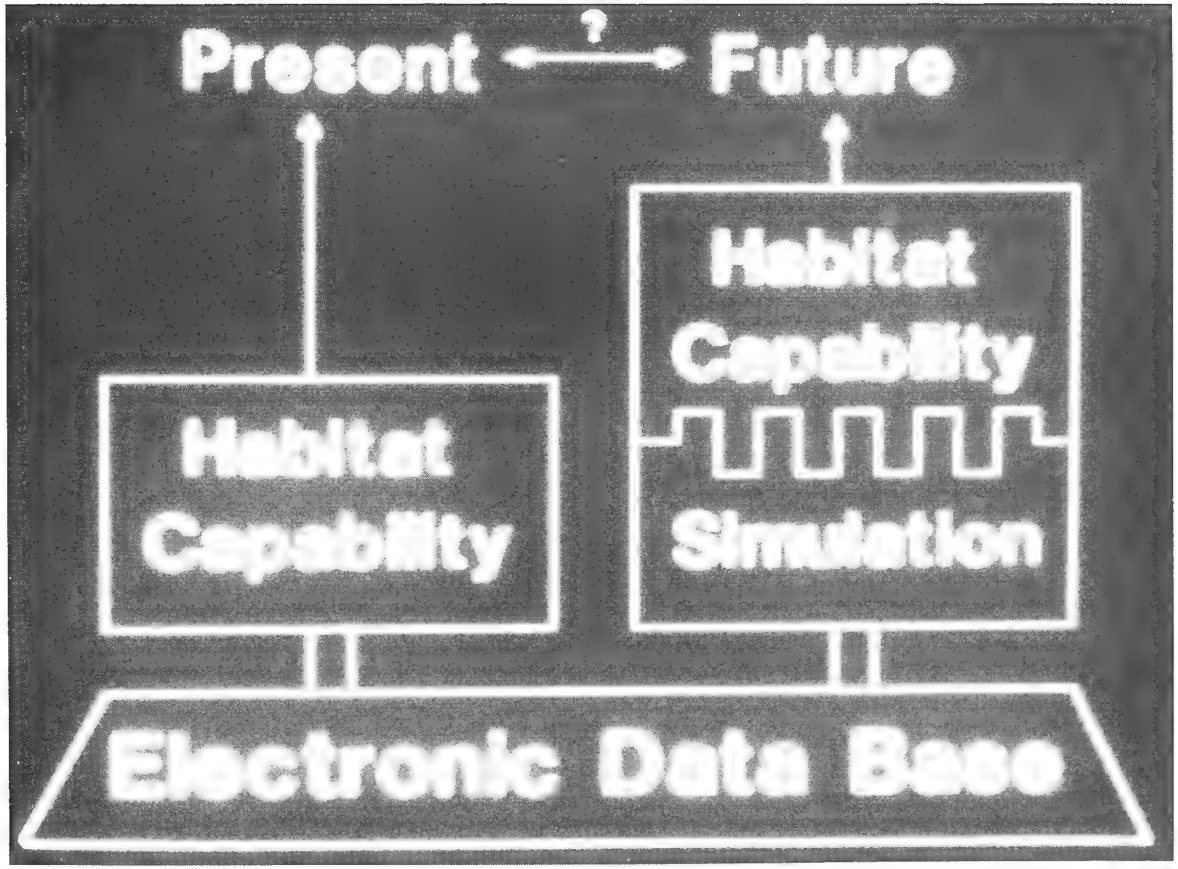
- Studies of monitoring techniques could not demonstrate any hourly variation in counts of birds during the first 5 hours of morning, indicating that timing of census taking is not critical.

- Research in California is identifying nonhabitat factors that affect songbird populations. In the Sierras, winter weather and not habitat is the dominant influence on winter bird populations.

- Scientists at the Southeastern Station have found that, to be used by fox and gray squirrels, uncut streamside strips in clearcut areas must be at least 160 feet wide and connected to an adjacent forest.

- Scientists at the Northeastern Station have developed a foraging guild classification for North American birds, based on major food, feeding substrate, and foraging technique. Managers need such a system to accurately consider many species simultaneously when evaluating impacts of habitat alteration.

- The Intermountain Station has developed a system to estimate elk hiding cover from standard timber-stand information. Output can be displayed in graphs or tables.



Research develops basic information and habitat capability models to predict future response of wildlife species, such as the ovenbird, to forest-management activities.

The publication "Rancher Response to Changes in Federally Permitted Livestock Numbers in Eastern Oregon" grew from the need to determine the actual changes ranchers make when provided an opportunity to increase the number of permitted livestock on Federal range. Previous modelling efforts of the Forest Service and other agencies have typically assumed direct linear relationships between base herd livestock numbers and permitted use, although changes in ranch operations that accompany shifts in permitted use have not been well documented. The Oregon Range Evaluation Project provided an opportunity to examine these shifts in private cooperator ranch operations.

First, the investigators determined how ranchers reacted to being given permission to adjust their livestock numbers through an increase in permitted grazing. Next, the study consulted ranchers who did not receive an increase in grazing permits, to find out how they anticipated shifting their livestock numbers if they were to receive an increased grazing allotment. The study also examined the response ranchers said would result from decreases in permitted use.

Findings indicate that not all ranchers who were given increases in permitted livestock use actually increased their herd size. One-fifth of these ranchers moved their existing herd to different summer grazing rather than increasing its size. The majority did increase herd size by increasing both cows and yearlings. The study also found indirect responses to increases in permitted livestock.

Ranchers acknowledged that additional winter forage was needed to sustain the increased herd numbers. Ranchers who did not receive the increase did not recognize many changes necessary to accommodate increased herd size. All ranchers not receiving increases thought they would increase herd size if given an increase in permitted use.

Responses to hypothesized cuts in permitted use followed patterns similar to those observed with the increase in use. Those who had an actual increase suggested more changes in ranch operations than those who had no experience with recent increases in permitted use.

Implications of the study relate to modeling of anticipated changes in ranch resources when permitted use increase or decrease. To model a simple, direct linear relationship between permitted use and base herd size leads to errors. The induced effects in ranch operation due to changes in permitted use must also be considered.

Changes in ranch operations induced by adjustments in permitted livestock numbers on Federal land are complex and difficult to predict.

New Guidelines Developed for Proper Grazing of High Sierra Mountain Meadows

Mountain meadows in the Sierra Nevada are areas where livestock, wildlife, and recreational activities concentrate. As such, they produce separate but mutually influenced products: use for any one product affects other products and uses. The mountain meadow manager's job is to find an optimal balance among often conflicting uses which assures maintenance of multiple-resource productivity.

Forest Service scientists found the basic requirements for mountain meadows are watershed and slope relationships which provide for an accumulation of fine-textured materials and geologic strata that promote constant water levels. They also found herbage production decreases as elevation increases, toward the extremes of moisture gradient, and as range conditions decline. Herbage production peaks when vegetation is at or near climax. Meadow type classification, meadow occurrence and development, and meadow seasonal aspects are summarized primarily from data presented in the Forest Service General Technical Report PSW-84.

Key factors in management of meadow grazing are carbohydrate reserves, weather, current use, and soil condition. Grazing too early or too late or both can critically reduce winter survival and spring growth of vegetation. Soil should be sufficiently firm when grazing starts that animals do not leave deep imprints; herbage should be sufficient to meet animal needs. Grazing should end while weather is conducive to regrowth and replenishing carbohydrate reserves.

Current use should aim to maintain leaf area near the optimum for photosynthesis and carbohydrate production. Leaving 55 or 65 percent of the average annual production on sites in excellent condition is suggested. Higher percentages of forage should be left on sites in poorer condition. The report also estimates range readiness dates for different elevations and for years of varying moisture status.

Proper grazing is possible on Sierra Nevada mountain meadows if consideration is given to elevation, moisture regimes, and current health of the specific meadow.

The Upper Rio Puerco Watershed in northwestern New Mexico was classified into 45 ecological phyto-edaphic (plant-soil) communities based on plant species-importance values. Species-importance values were calculated from the relative cover, relative density, and relative frequency values. The community descriptions consist of vegetation and soil surface characteristics; landform; soil series, association, or complex; ecological stage; and potential natural vegetation. The communities represented 11 vegetation series consisting of 2 woodland, 5 shrubland, and 4 grassland formations. Three soil orders, 27 soil series, 9 associations, and 3 soil complexes were identified. The combination of landform, vegetation, and soil were considered phyto-edaphic communities. A dicotomous key was developed for field identification.

Phyto-edaphic communities classified on an ecological basis allow for extrapolation of research results to similar environments and provide land managers a scientific basis for interpretation of ecological succession and for predicting phyto-edaphic community response to a management prescriptions. Management costs can be reduced by utilizing the phyto-edaphic community classification system to select for a particular treatment only those communities most likely to respond.

The ability of semiarid sites to respond to management practices can be predicted by a unique combination of vegetation, soil, and landform characteristics.

Converting Chaparral Shrubland to Grassland Increases Streamflow

Chaparral is the dominant vegetation on about 3 million acres of shrubland in the Southwest, mostly in central Arizona. In this dry climate about 95 percent of the precipitation is returned to the atmosphere through evaporation and through transpiration by the vegetation, leaving very little for streamflow. Scientists at the Rocky Mountain Station in Tempe, AZ, have been studying the possibility of reducing chaparral shrub density to increase the amount of water that reaches streams. But two important considerations regarding streamflow increases must be determined before a particular shrub-management practice can be recommended for wide application. First, on the positive side, how much additional water can be expected from removing the shrubs? Second, on the negative side, does this increase contribute to major flood flows and subsequent property damage?

Scientists have known for some time that shrubs use more water than grasses. Converting shrub communities to grass should leave more water for streamflow and still protect the soil from erosion. To test this theory, a 303-acre watershed was partially converted to grass (55 percent) in a mosaic pattern designed to favor wildlife, water quality, and landscape esthetics. Streamflow increased 2.68 inches per year, or 72 percent. Increases, evident in all seasons, were greatest in winter. Significant increases in water supply are possible if extensive shrubland is converted to grassland in a similar mosaic pattern.

A related study examined the contribution of increased flow to flood flows on two small chaparral watersheds by converting one to grass and comparing it with the other. Mean storm flow volume increased 224 percent, and mean peak flow rate increased 77 percent. The results indicate that large chaparral conversions in the Phoenix area would increase major flood flows by less than 4 percent.

Developing an understanding of commodity and noncommodity resource interrelationships on intensively managed forest range is a primary Forest Service research objective. Investigations to develop an understanding of forest range resource relationships are in progress at a number of locations within the Pacific Northwest, Pacific Southwest, Intermountain, Rocky Mountain and Southern Experiment Stations. Escalation in the number and intensity of demands placed on the Nation's approximately 550 million acres of forest range provide an increasing challenge for scientists to develop acceptable alternatives for integrated resource management. Although new and emerging critical information needs continue to arise, many significant recent accomplishments have been made by forest range scientists.

Timber management and land use influence forage production per acre and the total number of acres available for forage production. On commercial forestland in the States of Arkansas, Alabama, Louisiana, Missouri, Tennessee, and eastern Oklahoma and Texas, a Forest Service scientist found that forage is a function of forest type, growing stock volume of timber, site index, timber stocking level, and management activities such as burning and harvesting. Four forest types are modeled: planted pine, natural pine, oak-pine, and upland hardwoods. The model, FORAGE-SOUTH, is initialized on commercial forestland with Forest Inventory and Analysis data and on pasture and rangeland with Soil Conservation Service Natural Resource Inventory data. Future timber-management scenarios from the regional timber inventory model, TRIM, and future land-use changes from the southern land-use model are input to FORAGE-SOUTH. The impact of these activities on the forage production is examined over a 50-year time horizon.

The Forest Inventory and Analysis (FIA) Unit of the Intermountain Station established and inventoried ponderosa pine sites throughout Colorado and Wyoming during 1981-83. Range scientists from the Rocky Mountain Station, as part of a cooperative study with the Intermountain Station, reinventoried these sites in 1984. The goal of the study was to develop a regional forage production model for the central Rocky Mountains. Overstory canopy cover and abiotic site factors, such as soil and water, were considered in developing the regional model. Canopy cover was a highly significant predictor of total forage production in the resulting logarithmic model. Approximately two-thirds of the variation in total forage production was explained by the model.

Subterranean clover is a cool-season, nutritious forage legume that can be grown in the Southeastern United States. Available varieties grow best on well-drained sites and tolerate acid soil conditions, producing adequate forage without addition of lime if soil pH is 4.8 or higher. However, at least during the first few years, annual applications of at least 50 kg/ha of P_2O_5 and K_2) are needed to maintain good production. In addition, summer growth of competing vegetation must be removed annually in late August or early September by heavy livestock grazing, use of herbicide, or close mowing. Unlike other clovers, subterranean will reseed even if heavily grazed during the flowering

stage. Initial establishment under pine timber in the Southeast can be achieved by removal of hardwoods, prescribed burning, and broadcasting freshly inoculated seed on top of the soil in late October or early November when the soil surface is wet. Production of adequate forage before midwinter remains a problem, especially if unregulated use is heavy. Subterranean clover is preferred by cattle and deer. One-year nursery stock of longleaf, loblolly, and slash pines can be successfully planted in grazed, cutover subterranean clover pastures. Conifer survival varied with species of planted pine, but survival of planted pine was similar within species whether pines were protected from grazing by exclosures or completely exposed to grazing.

A long-term study conducted in the Blue Mountains of northeastern Oregon has shown that grazing significantly influences the development of forest vegetation

National forest lands like this stand outside Alexandria, LA, provide low-cost forage for thousands of head of livestock. Better understanding of the relationships between forest and range will improve our management of such lands for multiple uses.

following timber harvest. Summer browsing by deer and elk during the first few seasons after logging disturbance limit or preclude the establishment of abundant shrub seedlings and favor the development of a longer grass-forb successional stage. Eleven seasons after logging, shrub cover in the portion of a clearcut protected from grazing was 10 times that where deer and elk grazed. Similiar effects have been noted in partial-cut and unlogged stands. Minimal damage to either planted or naturally established conifer seedlings has been found.

The results of this research have made it obvious that patterns of past and present animal use are important factors to consider when classifying vegetation and characterizing ecosystem processes in these forests. They may also have important implications for the formulation of vegetation-management strategies that may affect timber, watershed, wildlife habitat, and other resource values.

Planned or unplanned, forest harvests and associated practices create mosaics of forage and cover that strongly influence the distribution and degree of forest grazing. By understanding and considering animal needs, managers have opportunities to manipulate the size, arrangement, and structure of habitats to either minimize grazing effect or utilize it as a subtle but effective management tool.

In a study conducted in the Black Hills of South Dakota and Wyoming, Forest Service scientists determined that 48 plants make up the diet of cattle. Cattle diets averaged 54 percent grasses, 17 percent forbs, and 28 percent shrubs-trees during the grazing season. Sedges and wheatgrasses were the most abundant plants in the diet throughout the season. Bur oak, ponderosa pine, and Oregon grape were common in the diet. Shrubs and trees made up 37 percent of the diet in September. When forage is widely available, in August, cattle diets are not very similar, indicating that cattle graze selectively. Public and private land managers will use these data to develop improved livestock-management plans with consideration of dietary needs and season of use by livestock.

Mule deer in the Sierra Nevada rely heavily on mountain whitethorn and deerbrush as summer forage. Forest Service scientists found annual production by deerbrush and mountain whitethorn shrubs in the south-central Sierra Nevada of California was related to shrub volume, volume squared, and mixed conifer overstory crown closure. Production increased as shrub volume and volume squared increased, and it decreased as overstory crown closure increased. Samples of shrub forage were also analyzed for calcium, phosphorus, crude protein, in-vitro digestible dry matter, gross energy, digestible energy, and sequential fibers. Overstory crown closure and shrub age had only minor effects on forage quality, but significant annual differences were found in several variables in both shrub species. Under conditions common to the southern Sierra Nevada, annual differences in precipitation may have been more important than available light in determining forage quality. Forage deficiencies in late summer may have a substantial adverse affect on newly weaned fawns.

Spring-run chinook salmon, a stock of great importance to sport and commercial fisheries of the West, spend more than 1 year growing in fresh water as juveniles before migrating to sea. Much of the rearing habitat for these fish occurs in streams on the national forests, but loss of both quantity and quality of habitat due to past logging, mining, and grazing, coupled with migration problems at hydroelectric facilities, has resulted in a decline of wild spring chinook stocks. Research is investigating ways to improve habitat conditions for these wild fish and other anadromous salmonids.

Cooperative research with the University of Idaho indicates that undercut stream banks are a preferred habitat for juvenile spring chinook in small streams. Results of the studies indicated that given a choice, 82 percent of the fish in the channel chose to reside in areas with simulated undercut streambanks. These findings suggest that natural undercut banks, or undercut banks simulated by artificial shelters or enhancement structures, are an important summer habitat component for juvenile chinook and should be recognized as such.

Improved rearing habitat for steelhead and chinook salmon can be achieved with mechanical imitations of underwater debris barriers and modifications of the natural stream bank.

Resistant obstructions in and along stream channels, such as large woody debris, bedrock outcrops, or rooted bank projections, are vital to fish habitat. They greatly diversify aquatic habitat by disrupting the even flow of water and sediment downstream and by causing pools to scour and spawning gravels to deposit. In the past decade or so, fishery managers have attempted to improve habitat by adding artificial structure in the form of logs, boulders, and gabion weirs, and by controlling inputs of large woody debris. Though the success of most of these efforts to increase fish production remains unknown, there have been some obvious successes and failures to create the desired changes in physical habitat. The success rate in a variety of streams can best be improved by understanding better how natural obstructions affect channel processes.

This year, scientists of the Pacific Southwest Station completed a study on how natural obstructions affect fish habitat in a California stream supporting runs of both coho salmon and steelhead trout. Large obstructions were found to stabilize the stream channel despite the large volumes of sediment transported downstream. The channel changed only where large woody debris had moved. Obstructions were important for the distribution of habitats as well. Of the pools where larger fish resided in summer, most (85 percent) were formed by scour around obstructions. Bars, where spawning gravel was stored, were deposited upstream and downstream of obstructions. These results highlight the need to maintain numerous, stable obstructions in fishery streams in order to keep a diverse and stable habitat.

Additional findings from this research provide specific guides to design of artificial habitat improvement structures. For example, results indicated that maximum scour depth for pool formation could be achieved by structures which extend above the stream banks and are one-third the width of the stream channel.

Future research in a variety of streams will broaden our understanding of the role of obstructions so that managers can better duplicate how natural processes form diverse and productive habitats for fish.

In this shot from Bald Mountain Creek, in California, natural obstructions form a lateral scour and then a plunge. Studies of how logs and boulders create fish habitat are providing information on how to design fish habitat improvements.

Bicycling continues to be an important activity in urban forest areas, and there are strong demands for additional trails. Existing forest preserve trails in the Chicago area are heavily used, with up to 3,000 bicycles passing a given point per day. Peak flows may reach 500 bicycles per hour on Sunday afternoons. Management of existing trails and the construction of new ones pose important challenges to urban forest resource managers.

In a cooperative research effort carried out by the North Central Station and Southern Illinois University, trail users identified which trail attributes were most important to them and then indicated their level of satisfaction with trails that had varying combinations of attributes. A model was then developed that predicts user satisfaction with a trail, given characteristics of the trail surface, length, distance from home, terrain, and variety in the surrounding forest landscape. The model suggests that trail surface and distance from home are particularly important to bicyclists.

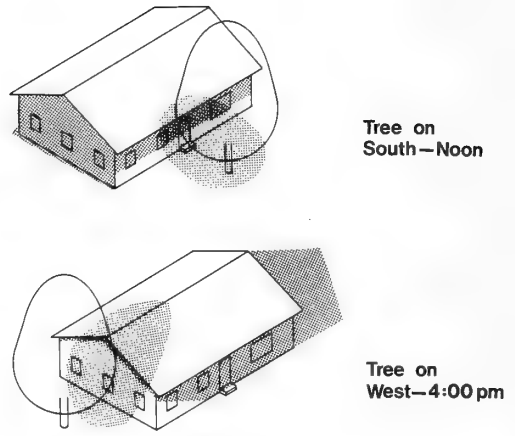
The model enables planners and managers to predict changes in user satisfaction that are likely to accompany changes in existing trails or the construction of new ones--before expensive alterations are made.

Building new bike trails or reconstructing old ones is an expensive business. In a joint study with Southern Illinois University, we polled cyclists to find out what trail qualities appealed to them the most. This information will save us money in the future as we continue to invest in improvements to the recreation facilities on our national forests.

If you want to save energy for heating and cooling of your home, it's important to carefully choose where you plant shade trees in your yard. Forest Service researchers at the Northeast and Pacific Southwest Stations have taken some long strides toward development of improved guides for optimizing the pattern of shade on houses throughout the year. Computer programs SOLPLOT and SPS were developed to help in selecting the optimum planting location. The computer programs, developed to give optimal control of sunlight and shade on windows, graphically illustrate shade location and show energy saved. These programs are now available for either mainframe computers or microcomputers.

The effectiveness of trees to provide shade in summer and permit sunlight penetration through the crown in the winter was found to vary by species, tree shape, tree density, and length of in-leaf season. These traits coupled with information on geographic location, solar radiation, and wind all influence the energy budget for a dwelling.

Research suggests that the maximum potential annual effect of trees on energy use in conventional houses is about 20 percent compared to energy costs for the same house in the open. While there is no clear choice of best species or location design for any specific house, there are usually numerous alternatives that will save energy and suit the homeowner.



Homeowners can achieve significant energy savings by planting trees where their shade will be most beneficial at "problem" times during the day.

New Seed Technology Makes Native Plants More Available for Resource Rehabilitation

In many Western States the wildland seed market comprises a significant fraction of the commercial seed industry. Wildland species are used as ornamentals, as plant materials for revegetation of range and wildlife habitat, and in roadside and other disturbed-site plantings. Growing demand for seeds of wildland species has increased the need for reliable information on seed quality. Official testing procedures enhance the validity of laboratory assessments regarding the value of such seed for planting.

Research designed to improve methods for evaluating the quality of seed for wildland planting has resulted in the adoption of official testing procedures by the Association of Official Seed Analysts for six important range species. Official testing procedures will be proposed for adoption for approximately 20 additional species in the next 18 months. The project--a joint undertaking of Utah's Department of Agriculture and Division of Wildlife Resources and the Intermountain Station's Shrub Sciences Laboratory--should increase the reliability of seed quality test results and improve communication between buyers and sellers of wildland seed.

In addition, the research is yielding a wealth of basic information on the germination biology of key shrub and forb species. A knowledge of germination response patterns and how they vary within widely distributed species such as antelope bitterbrush, big sagebrush, or rubber rabbitbrush will be useful in enhancing artificial seeding success with these species. Scientists are identifying between-population germination differences and relating them to the probability of successful seeding on specific site types. The research represents an aspect of plant materials evaluation which could lead quickly to significant management applications.

Forest topsoil can be used as a seed source for native species in reclamation and revegetation of surface-mined lands in Appalachia. Seeds that naturally occur in a soil and that have accumulated for years are called the "seed bank." The seed bank from a forest soil in the Cumberland Mountains of Tennessee supplied 84 kinds of native or naturalized pioneer plant species, including five kinds of trees. The plants were grown from a thin layer of topsoil spread over a surface-mine spoil. When seeds from a commonly recommended reclamation ground-cover mix (three grasses and Sericea lespedeza) were added to the topsoil, the natural species in the seed bank did poorly. Growth was stunted, and the number of naturally occurring species was reduced.

The natural seed bank community produced greater aboveground plant biomass and held on to more nitrogen, phosphorus, potassium, calcium, and magnesium than did the reclamation mix or a combination of the seed bank and reclamation mix.

The reclamation mix established good ground cover more quickly than the seed bank, but the differences were insignificant 16 weeks after establishment. The seed bank, or native species community, developed a deep, strong root system that improved the stability of surface-mine spoils.

Use of topsoil seed banks in Appalachia can greatly enhance the diversity of plant communities and accelerate succession to more stable conditions on disturbed lands.

Atmospheric Deposition Research Enhanced Through Scientific and Technical Exchange With Germany

Since September 1984, forestry researchers from the United States and the Federal Republic of Germany have cooperated to determine the role of air pollution and acid precipitation in forest damage. Both countries have similar research programs but different strengths. Onsite visits, firsthand discussions with colleagues, and exchange of scientific materials have given American and German scientists greater understanding of the complexities involved than either group could have reached alone. Although only 2 years old, this team approach has saved hundreds of thousands of dollars in research time and development and is already producing significant findings.

Examples of activity under this exchange include (1) a joint research program on wood biology between scientists at the Northeastern Station and at the University of Hamburg, and (2) a joint evaluation and refinement of German survey methods used to assess atmospheric deposition damage by members of the Forest Service Forest Pest Management Group and faculty of the University of Freiburg.

Study results on the anatomical and physiological parameters in healthy and declining fir were presented at and published in the proceedings of the 18th World Congress of the International Union of Forestry Research Organizations, held in Yugoslavia. A publication summarizing forest-damage inventory techniques used in West Germany and their applicability to forests in the United States was published within 6 months after the respective exchange visit.

This bilateral agreement, entitled "Cooperation in Agriculture Science and Technology between the United States and the Federal Republic of Germany," is an excellent example of what can be accomplished through joint efforts of the scientific communities of two nations.

When Americans think "forest," they probably visualize the pristine environment of our alpine and subalpine wilderness ecosystems in the West. But while these wilderness areas may seem far removed from civilization, air pollution affects many of them. Managers of these areas need to know how the air resource is changing and how specific changes are likely to change other qualities of the wilderness ecosystems they are responsible for. Forest Service scientists are determining how air pollutants are affecting the plants, animals, air, soil, and water of alpine and subalpine ecosystems. They are examining how pollutants are deposited in sensitive ecosystems, how they are concentrated in winter snows and released during spring runoffs, and how the natural life cycles of sensitive species are colliding with the cyclical release of pollutants into their habitats.

Forest visitors are often disturbed to find smoke, whether from a naturally occurring fire or from an ecologically sound prescribed fire. In the case of prescribed burning, visitors have the right to know that forest managers are creating the least amount of smoke possible while meeting the objectives of the prescibed fire. Forest Service scientists have long provided knowledge relating to fire safety, but now they are also developing the knowledge needed to assure that minimum smoke is being created by the positive use of fire. Basic questions about what to burn, when to burn, and how to burn--to limit smoke generation--can now be answered, thanks to the research findings.

People visiting forests near large population centers frequently notice visible effects of air pollution on forest trees. More than two decades of research have made it possible to explain many of the observed effects, identify the pollutant causing specific damage patterns, demonstrate appropriate dose-response relationships, and develop forest-survey techniques that allow much earlier detection of pollution damage by trained observers. In addition, we now understand a sequence of pathologies that begins with air pollution-caused tree weakening. The knowledge gained about the effects of long-term air pollutant exposures provides a

fundamental basis for determining pollution effects of lesser magnitude and duration at sites farther removed from urban pollution centers.

The combined research results of many Forest Service scientists over a period of several years form the basis of air resource management in the Agency. Worldwide concern about forest productivity and health as related to atmospheric changes is growing. Concern about how forest management practices affect the atmosphere locally, regionally, and globally is growing also. Forest Service research findings are viewed as the foundation upon which to build international efforts to better understand forest-atmosphere interactions and to treat air as a forestry resource.

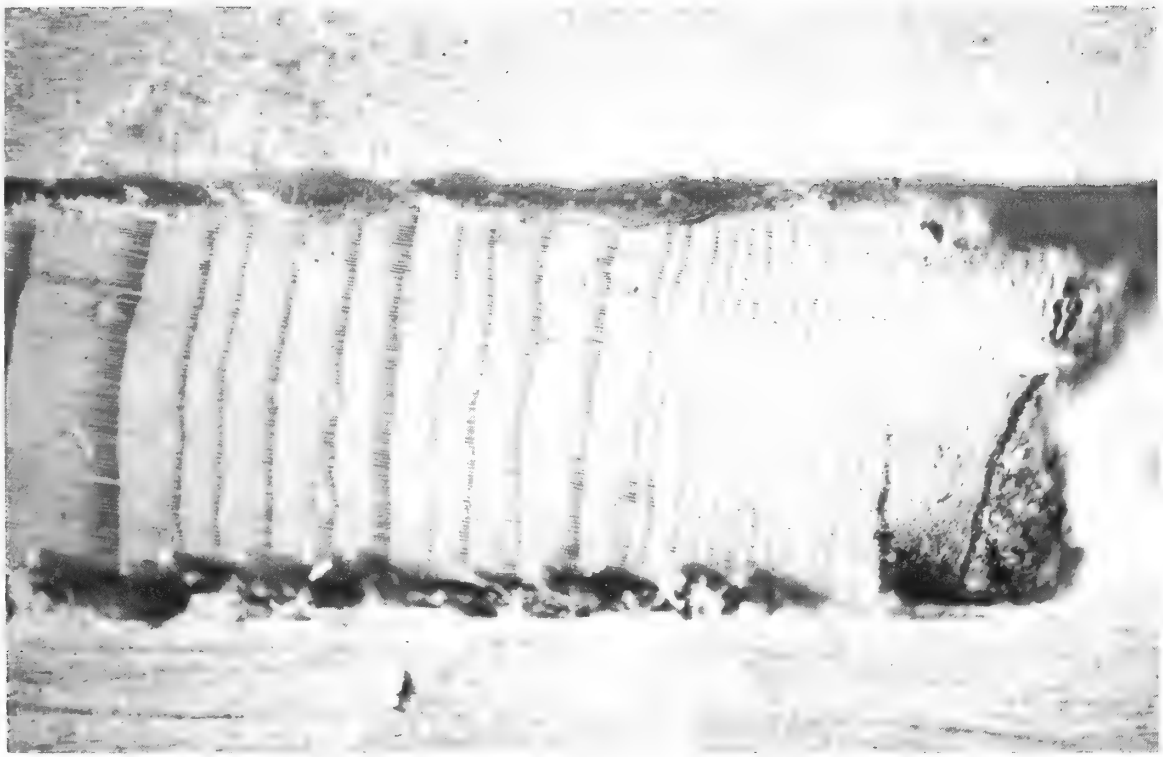
Forest Service scientists are measuring particles deposited from the atmosphere, such as acidifying materials, to better understand their effects on forest ecosystems.

Previous studies have documented the impact of prolonged exposure to ozone on the growth of ponderosa and Jeffrey pines in montane forests adjacent to the Los Angeles Basin, where the highest concentrations of ozone in North America occur. Ozone concentrations are much lower in the southern Sierra Nevada (maximum hourly concentrations of 0.15 parts per million) but are relatively high compared to most regions of North America. Symptoms of ozone injury to pines have been recorded in the area, but no data are available on growth impact.

Growth of Jeffrey pines at sites with symptoms of ozone injury (exposed) was compared to growth at sites with no symptoms (control) at Sequoia and Kings Canyon National Parks. Growth impact was determined by tree-ring analysis, with ring-width data standardized to remove age- and size-related trends. Growth index values were then used to compare growth on a relative scale.

Growth index values for exposed trees were 11 percent less than those of control trees since 1965. Prior to 1965, the exposed trees had a higher growth index than the controls, indicating a change in relative growth patterns since that time. Trees larger than 40 cm in diameter and more than 100 years old appeared to have a greater growth reduction than younger trees. Ozone-stressed trees were more sensitive to variation in precipitation and temperature than the controls, suggesting a change has occurred in the relationship between growth and environment in trees with symptoms of ozone injury.

These results are the first evidence of tree growth reduction associated with ozone injury in western North America outside the Los Angeles Basin.



Before several years of ozone exposure, the Jeffrey pine from which this core was taken exhibited good annual growth. Lately, however, the annual rings are much closer together. Growth index studies in the Sequoia and Kings Canyon National Parks indicate that older trees experience greater growth reductions due to ozone injury than younger trees.

The rugged alpine and subalpine wilderness areas of our western mountains are one of America's great natural treasures. While the very survival of such ecosystems in some of the most inhospitable of natural environments testifies to their ruggedness, they are actually quite fragile in terms of their ability to withstand potential damage associated with human-caused pollution. Those pollutants, carried to the wildernesses by the atmosphere, consist of a wide variety of potentially damaging chemicals. Because the materials of concern are carried by the atmosphere and deposited on the ecosystems, scientists term the phenomena "atmospheric deposition." The most worrisome class of pollutants is the ones that are acid. They are deposited dry (in particles) and wet (incorporated in falling rain and snow and in fog and frost).

Rocky Mountain Station scientists and their cooperators have developed new techniques for characterizing the effects of air pollution on wilderness ecosystems. They have also developed protocols for consistent description of the current conditions of the subject ecosystems. Included are measures to quantify the atmospheric environment, soil and geology, aquatic chemistry, and aquatic and terrestrial biota. Now, for the first time, a wide variety of scientific investigators and other interested parties will have a set of consistent standards on which to base future work.

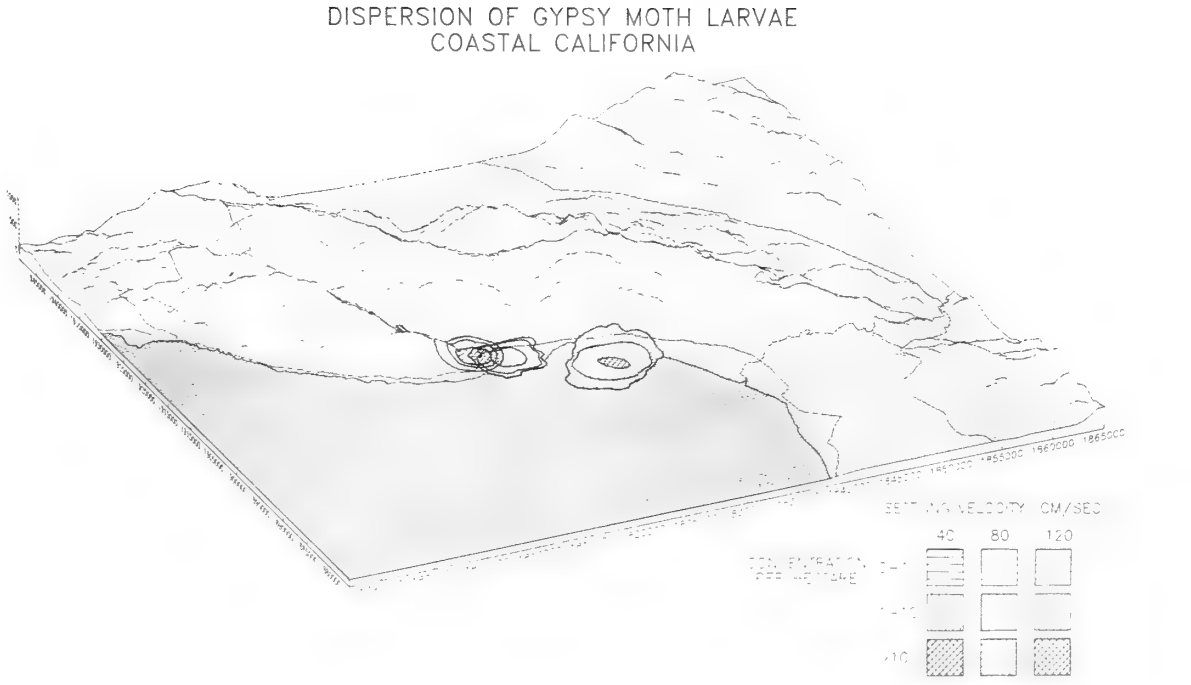
Many years of research lay ahead to determine specific cause-and-effect dose-response relationships between specific pollutants and individual ecosystem effects, but this protocol establishment effort will provide a firm scientifc foundation for those years of effort.

This device collects cloud water for measuring atmospheric deposition in wilderness areas.

Meteorology Research Provides a New Way To Track Movements of Gypsy Moth Larvae

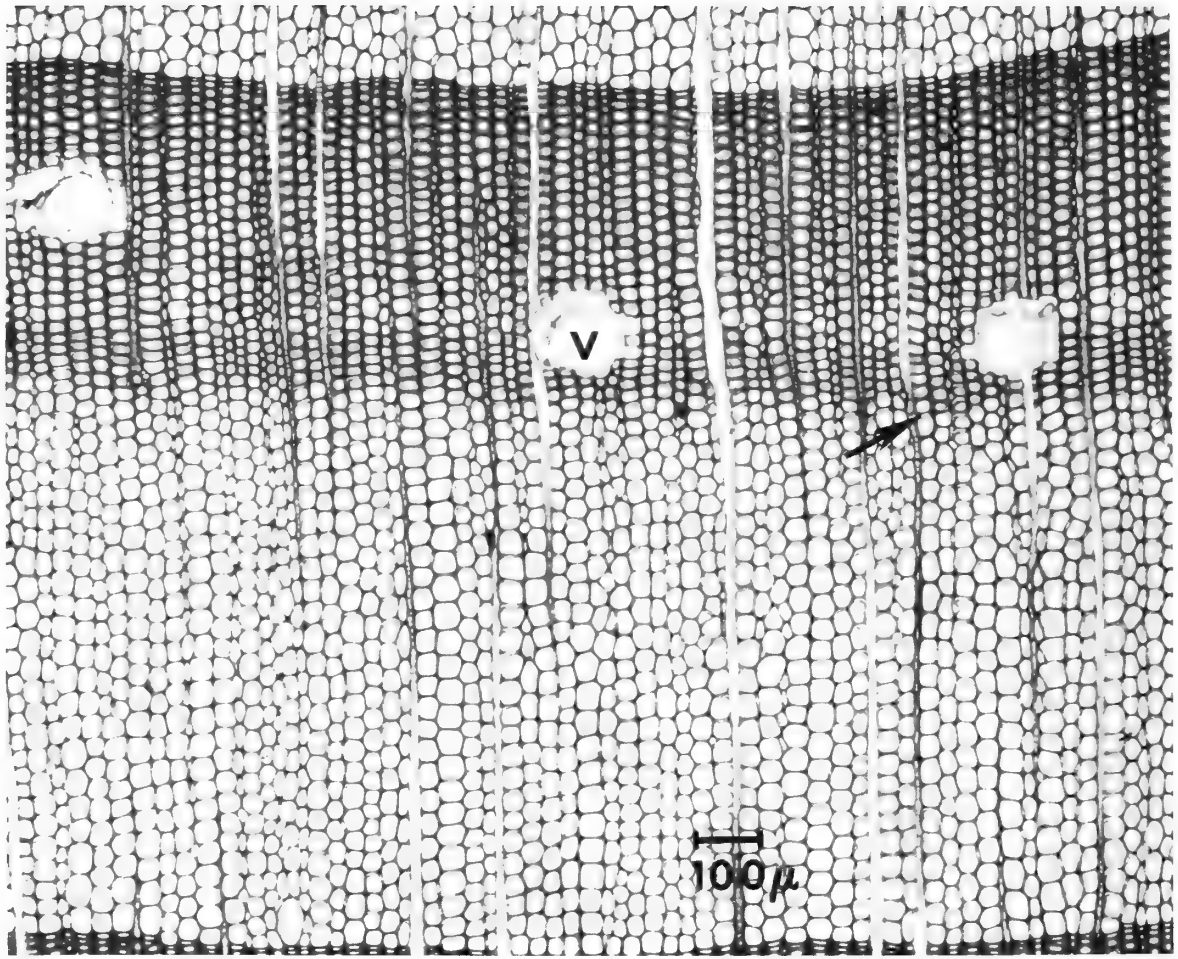
When a new gypsy moth infestation is found, the immediate question is, how rapidly and far will the insects spread? The answer to that question is a major factor in determining what procedures should be used to combat the infestation and what the cost of those procedures will be. Studies of windborne larval dispersion were conducted in the early years of this century, but until we could predict the behavior of changing currents of wind that bore the moth larvae, we could not make practical predictions of windborne dispersal.

Scientists at the Pacific Southwest Station have developed computer wind models that combine with knowledge of gypsy moth life cycles to predict the spread of the moth from a newly discovered infestation. The computer models were originally developed to portray how the wind would affect forest-fire spread and dispersion of smoke. By making modifications in those models and inserting information on the dynamics of windborne larvae, our scientists were able to use computer graphic simulations to show the probable spread of the gypsy moth. The computer models begin with a terrain base and develop a wind flow field. Then, based on settling velocities of the moth larvae, the models display probable concentrations of moth larvae per hectare on a map of the outbreak area.



This computer-generated topographic map shows various concentrations of gypsy moth larvae as wind-dispersed throughout the Los Angeles Basin.

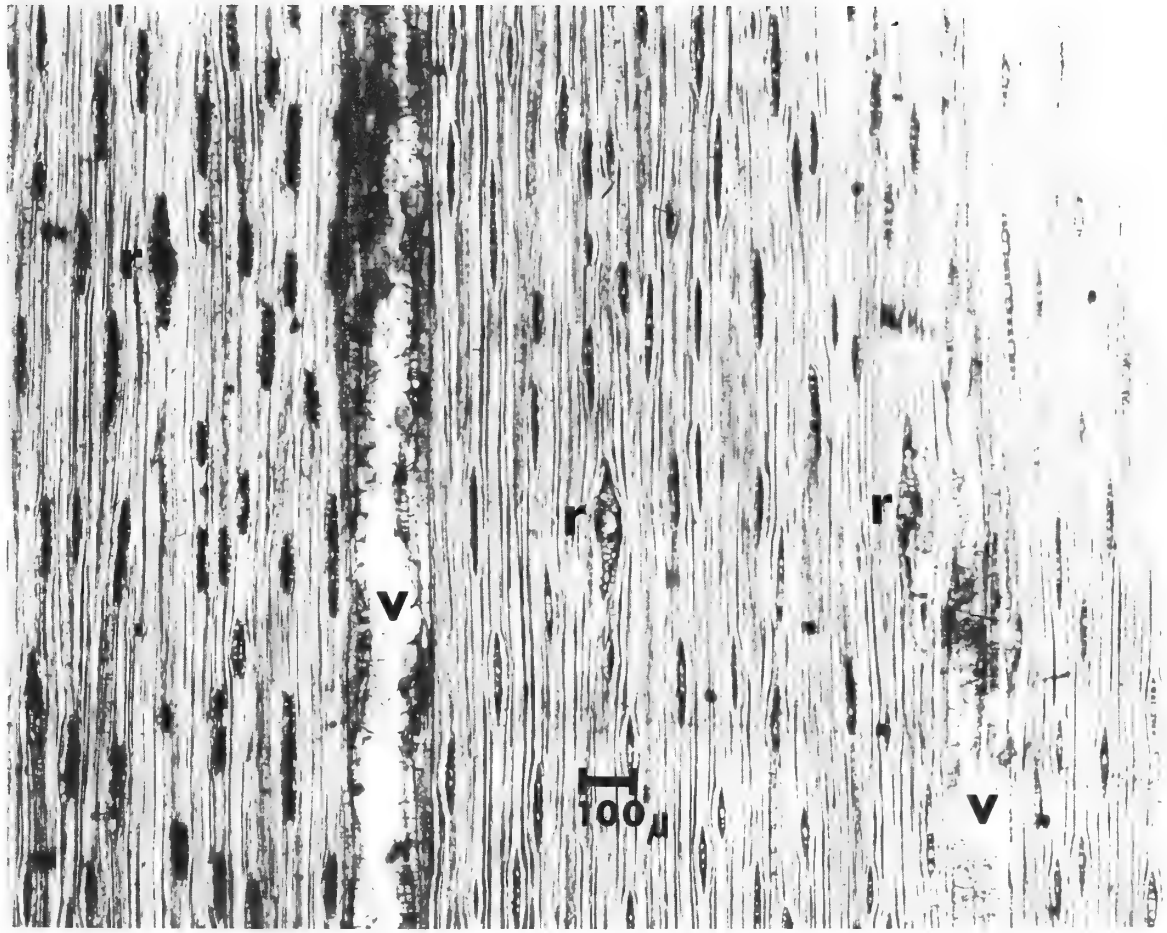
A Southern Station scientist has proposed a general hypothesis about tree resistance to attack by the southern pine beetle (SPB), based on knowledge of beetle activity and application of a concept formulated years ago to predict or explain plant behavior. The concept is known as plant growth-differentiation balance--a balance between the plant's use of energy supplies either in (1) cell division and enlargement (growth), or (2) changes in cell chemistry and form (differentiation). According to the concept, environmental conditions that limit growth but do not adversely affect energy supplies and transport in pines favor differentiation over growth. Oleoresin production is one of



Cross section of loblolly pine stem wood showing one annual ring. Larger thin-walled cells (light band, known as earlywood) are characteristic of wood formed in the spring and early summer, when growth processes predominate. Thick-walled cells (dark band, known as latewood) are typical during the summer, when growth has slowed and differentiation processes are favored. Note that the dark latewood zone contains vertical resin ducts (v), which store most of the oleoresin the pines use to defend themselves against southern pine beetle. The light earlywood zone (formed during the rapid growth period of spring) contains no such resin-carrying ducts.

several differentiation processes. The hypothesis connects long-observed seasonal changes in beetle behavior with seasonal changes in the way trees use the energy available to them.

Pine trees defend themselves against SPB attack primarily by exuding gooey oleoresin and pushing out the beetles as they try to penetrate the bark. In the spring, when growing conditions are optimal, trees apply their energy more to growing than to producing oleoresin. With limited resin available, the trees are especially susceptible to beetle attacks. But in mid to late summer, moderate water shortages "convince" the trees to shift more of their energy to differentiation.



Freehand longitudinal (tangential) section in loblolly pine latewood, showing a number of radial resin ducts (r) and portions of two vertical ducts (v). Note that the vertical ducts, the principal reservoirs of a tree's oleoresin supply, are several times larger in diameter than the radial ducts. When beetles attack during the formation of earlywood, resin must flow relatively long distances through the small-diameter radial ducts to wound locations. But when they attack during the formation of latewood, resin can move in quantity to wound sites, greatly enhancing the trees' ability to repel beetles.

Synthesis of oleoresin increases, and the trees are much better able to fend off attacking SPB.

The beetles change their behavior drastically around the same time that moderate water deficits stimulate the pines to grow less and differentiate more. Instead of dispersing in the forest, as the insects do in the spring when they can easily establish new infestations, SPB reaching maturity in the summer tend to concentrate on trees at the edges of existing infestations, attacking en masse. This behavior enhances the potential success of attacking beetles when tree resistance is high.

Although the general hypothesis helps us to better understand observations and the results of past research on SPB-tree interactions, it is only a first step. The growth-differentiation balance concept provides a sound basis for bark beetle research heretofore lacking. Most importantly, it dispels the long-held idea that moisture stress is inherently bad for trees and good for beetles. Actually, the timing and degree of moisture stress largely determine its effects; and, surprising to some, a little stress can help trees fight insect enemies, such as the SPB!

The concept of plant growth-differentiation balance has long been part of the general knowledge in agronomy and horticulture. Now, it appears to be relevant and applicable to a wide range of insect-plant interactions and to provide a sound rationale for researchers studying ecological and evolutionary theory of plant defense against herbivores.

Bluestain in Pines May Be a Marker for Southern Pine Beetle Outbreaks

Outbreaks of the southern pine beetle occur unpredictably and are a serious threat to the pine forests in the Southern United States. Current outbreaks in Texas and Louisiana are the worst on record. Recently, researchers have found a relationship between the presence of a fungus and bark beetle population levels that could help in predicting the trend of an outbreak.

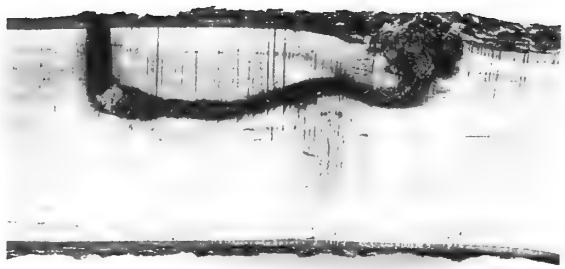
The southern pine beetle carries a number of fungi, including the bluestaining fungus, Ceratocystis minor, long recognized as a common associate of the insect. The fungus grows into the sapwood and causes the characteristic stain seen in beetle-killed trees. Ceratocystis minor is known to kill pine trees, and many researchers believe it must be present in order for the beetle to overcome healthy trees.

Experiments conducted in Texas and Louisiana show that trees killed by the southern pine beetle generally had less bluestain in areas where the beetle infestation was most severe. Under outbreak conditions, some beetle-killed trees may not have bluestain at all. These findings may be of practical importance as a diagnostic or predictive tool for pest-management specialists. Stain caused by this fungus is easy to recognize, and measurements of the amount of stain present in trees killed by the southern pine beetle may prove useful in predicting the onset or collapse of bark beetle epidemics.

This loblolly pine was killed by the southern pine beetle. Removing the bark reveals both the insect's S-shaped galleries and dark patches of stain caused by the fungus Ceratocystis minor. Though the beetle and C. minor often travel together, recent research indicates that very high southern pine beetle populations kill trees without any help from bluestain fungi.

Pecan and ten species of hickory are native to the Eastern United States. Most of these trees are economically important in timber production, commercial nut production, or as ornamentals, and serve as an important food for wildlife. Although a number of insects, including borers, pruners, and girdlers, are injurious to pecan and hickory and are widely distributed, they seldom threaten trees over large areas. Damage tends to be local, in nurseries, nut-producing groves, young timber plantations, and ornamental plantings. Damage includes a loss of tree form; reduced nut crops; defects in wood that reduce its value for lumber, veneer, and other products; loss of esthetic beauty of shade and ornamental trees; destruction of grafts; and, sometimes, death. Damage can be minimized by good management, especially through cultural practices that maintain and promote tree health.

"A Guide to the Insect Borers, Pruners, and Girdlers of Pecan and Hickory" should be of interest to a wide audience, including forest managers, nut growers, entomologists, extension agents, pest-control specialists, educators, and homeowners. This publication explains how to identify the insects that attack shoots, branches, trunks, and roots of pecan and hickory, and how to prevent or reduce the damage they cause.



The gallery of a hickory borer, in a cross section of hickory.

A nuclear polyhedrosis virus of the Douglas-fir tussock moth (DFTM) has been developed as a safe microbial insecticide for use in suppressing DFTM outbreaks. This is the first such virus registered by the Environmental Protection Agency for use against a forest insect pest. Currently, we produce it on living laboratory colonies of the tussock moth. Although DFTM is the natural host of this virus, there are many reasons why it is not the best host for production of the microbial insecticide. Rearing the DFTM is expensive because fastidious manual care by trained personnel is required to assure a successful production schedule. Hairs on the larvae and cocoons can cause irritations or allergic reactions in laboratory workers. Protective clothing and filter masks are required for the safety of production-plant personnel. The tussock moth has a long life cycle that includes overwintering in the egg stage. This extends the generation time to several months and impedes production.

In 1986, scientists at the Pacific Northwest Station successfully concluded a search for a substitute host to grow the DFTM virus. The cabbage looper has many advantages over the DFTM as a medium for production of the virus. It has a brief life cycle (24 days from adult to adult) and yields a virus product of much higher potency. The looper's hairs do not cause allergic reactions, and the insect is much easier to handle and rear in the laboratory than the DFTM.

Because of these advantages, and since large-scale rearing procedures and facilities for the cabbage looper have been in use for many years, the incentive for commercial production and registration of the virus by private industry is much improved. The Forest Service can divest itself of the expense and inconvenience of production and registration if private industry decides to fill that role.

The Douglas-fir tussock moth (DFTM) is the most serious defoliator of conifers in the West. It can be suppressed with chemical insecticides, or by introducing the nuclear polyhedrosis virus into DFTM populations. Researchers at the Pacific Northwest Station have developed a way of growing the virus in an alternate host insect--one much easier to rear in the lab. This breakthrough should make it much more economical to use the virus for DFTM control.

The western spruce budworm, a serious insect defoliator of western conifer forests, can cause extensive damage under certain forest and stand conditions. Outbreaks of the budworm occur in dense, multistoried stands composed mostly of host trees that are shade tolerant, such as grand and white firs and Douglas-fir. These stand conditions occur over much of the range of budworm, primarily because (1) the frequency of forest fires has been very low compared to pre-1910 periods, allowing the shade-tolerant species to proliferate; and (2) selective harvesting practices have removed much of the shade-intolerant or "seral" conifer species, such as ponderosa pine and western larch, which are not primary hosts for the insect.

Reducing the habitat that favors budworm epidemics by using silvicultural methods is an effective long-term approach for dealing with this pest in the northern U.S. Rocky Mountains and perhaps elsewhere. Even-aged silvicultural practices, such as clearcutting and seed-tree and shelterwood cutting, can be used to create conditions unfavorable to budworm. Shade-tolerant hosts are removed and replaced with the fast-growing and productive seral pines and larch. Stands like this are poor for budworm but excellent for timber, wildlife, and recreation. These stands usually are not multistoried, and stand density is easily controlled to optimal levels. In prime budworm habitat, conversion of uneven-aged host stands to mosaics of even-aged stands will dramatically reduce the budworm problem over the length of a single rotation.

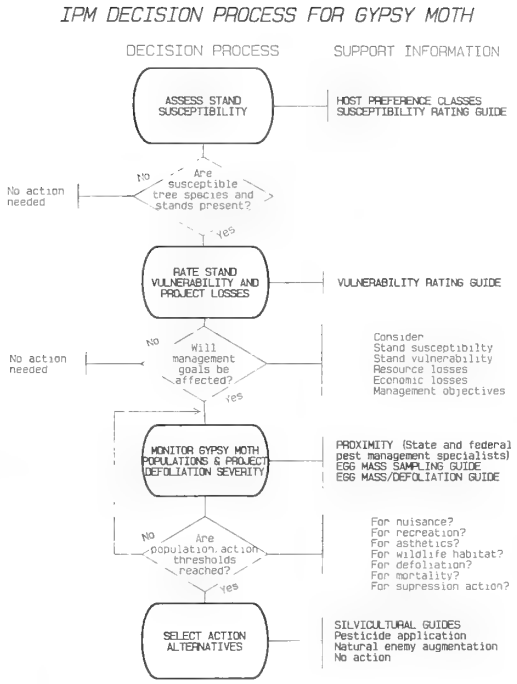
Whether or not susceptibility to and damage by the budworm can be reduced forestwide will depend on forest economics, the political climate, and the willingness of forest managers to make provisions for budworm control in their forest-management planning.

Douglas-fir is extremely susceptible to western spruce budworm attack. Therefore, in areas where it is the climax species, Douglas-fir should be harvested and a few seed trees of less susceptible species, such as pine and larch, should be left behind, to provide a next generation of trees that will be less likely to appeal to the budworm. Since this photo was taken, the overstory of seed trees has been removed. What remains is a thrifty young stand with very low susceptibility to western spruce budworm. Even-aged silviculture like this--not extensive spraying--is the key to effective budworm management in the West.

The gypsy moth is a threat to millions of acres of forest land outside its present territory in the Northeastern United States. Some species can withstand only 1 year's defoliation; if the gypsy moth hits stands with these species again in a subsequent year, nearly all the attacked trees succumb. As this destructive defoliator spreads into uninfested forests, managers must search for ways to cope with the invasion. The course of action taken will be guided by an understanding of how much tree defoliation may occur, what the losses may be following defoliation, and how these losses will affect management objectives and action alternatives.

Forest Service scientists have described an integrated pest management (IPM) decision process to help forest managers select options for reducing stand and forest impacts from gypsy moth defoliation. The IPM decision process leads the manager faced with a gypsy moth threat through a step-by-step approach for determining tree and stand susceptibility and for estimating which stands are likely to be most heavily damaged. Once these determinations are made, the manager must decide if the amount of loss projected will jeopardize goals for that site. If the answer is yes, insect monitoring should be instituted to determine the proximity of any infestation and the level of local moth populations. Managers then select appropriate actions based on projected losses, treatment thresholds dictated by primary forest use, and compatibility with management goals.

Heavy timber mortality, particularly in oak stands, follows the gypsy moth's progress in the East.



Managers can use the flowchart to guide their decisions about whether--and where--to spray for tree protection.

Lodgepole pine is one of the most important conifer species in the Western United States. It ranks fourth among timber types in area covered--13.3 million acres of commercial forest land in the West. These forests provide wood products, cover for watersheds, forage for livestock, habitat for wildlife, and scenic and other recreational values. But lodgepole pine has a formidable enemy in the mountain pine beetle (MPB), a native insect. It is the most aggressive bark beetle attacking these pines and has decimated extensive areas of lodgepole in the West. During an MPB outbreak, millions of trees can be killed in 1 year. The beetle also attacks and kills ponderosa, sugar, and western white pines.

MPB-caused losses can have catastrophic impacts, depending on landowners' objectives. From the standpoint of timber production, beetle infestations seriously affect the sustained yield and even flow of wood products. Outbreaks disrupt management plans and affect local and regional economies. They increase fire hazards and diminish recreational values and esthetics.

In the course of studying MPB epidemics over the past 20 years at the Intermountain Station, we have greatly increased our understanding of factors influencing the dynamics of beetle populations. This knowledge has led to the development of (1) methods to identify stands susceptible to beetle infestation,

An adult mountain pine beetle, no bigger than a grain of rice.

(2) techniques to predict lodgepole pine losses caused by MPB, and (3) silvicultural prescriptions to help prevent or reduce these losses.

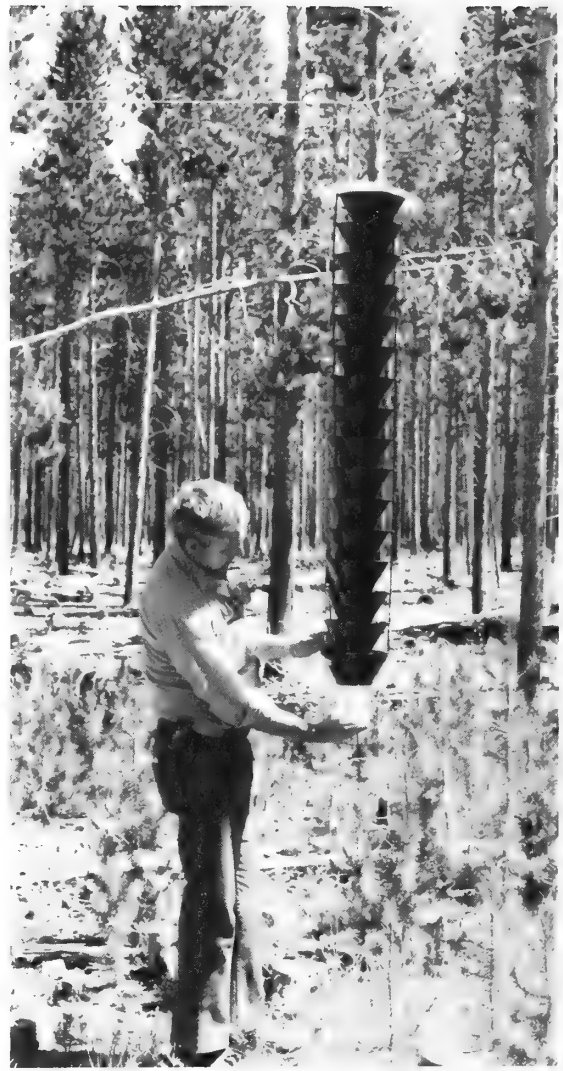
The extensive research on MPB dynamics has greatly increased our understanding of beetle biology and behavior and the insect's interactions with the host tree. This research has been pivotal in clarifying the reasons why trees and stands become susceptible to attack. We found that beetle outbreaks are strongly related to tree and stand conditions. In an outbreak, the beetle first kills the older, large-diameter trees usually associated with unmanaged mature and overmature stands. It survives and reproduces best in these trees. Identifying stands having characteristics conducive to beetle attack permits managers to treat those stands before outbreaks can get started. Methods for rating the risk of beetle damage are based on characteristics that promote outbreaks. Techniques have been developed and are now in use to determine the expected rate and amount of tree loss once a stand becomes infested. Using modeling

Two stands of lodgepole pine from northern Utah's Wasatch National Forest illustrate the difference silvicultural management can make. The unthinned stand on the left sustained heavy losses to mountain pine beetle; the adjacent thinned stand incurred no damage.

tools, the resource manager can estimate tree and volume losses per year and how long an infestation will last on different habitat types.

The most satisfactory long-term solution to the MPB problem is preventive management based on manipulation of tree and stand conditions to reduce vulnerability to beetle infestation. This is true because little can be done to reverse the trend of an MPB outbreak once underway. Silvicultural guidelines now available provide the most efficient and environmentally suitable tools for achieving such a long-term solution.

The work that remains is to increase our understanding of beetle dynamics when populations are at endemic (low) levels. This research is well underway and will contribute significantly to understanding the process of transition from endemic to epidemic populations. Data already in suggest that the MPB is a "follower" during endemic periods: it prefers lodgepole pines already infected by root rot or secondary bark beetles. This change of MPB from "leader" during epidemics, where it initiates the attack, to "follower" during endemic periods, where it follows on the heels of other pest invasions, appears to be a reflection of changes in beetle genetics. Once we have a better grip on MPB dynamics at low levels, we should be able to formulate sound preventive strategies to curb losses by this major forest pest.

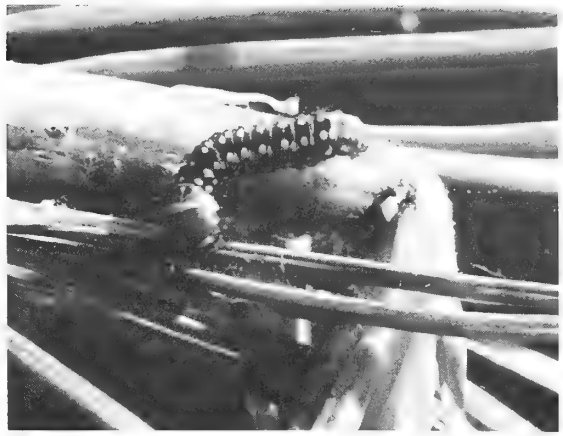


On the Wasatch National Forest, scientists are using traps baited with pheromones and kairomones to study beetle population numbers after thinning. They are also measuring the microclimate in unthinned lodgepole stands to determine its effect on the beetle.

The spruce budworms are ranked among the most serious forest pests in North America. Tree mortality, top killing, reduced growth rates, lowered timber quality, and failure of stand regeneration are serious consequences of unmanaged outbreaks. In 1977, the U.S. Department of Agriculture and Canada's Department of the Environment agreed to cooperate in an expanded and accelerated research and development effort, the Canada/United States Spruce Budworms Program (CANUSA), aimed at the spruce budworm in the East and the western spruce budworm in the West. The objective of CANUSA was to design and evaluate strategies for controlling the spruce budworms and managing budworm-susceptible forests, to help forest managers attain their objectives in an economically and environmentally acceptable manner. This international cooperative program, which ended in 1984, provided forest managers with new and improved information and technology for dealing with the spruce budworms.

Results of the program have been made available through a comprehensive technology transfer effort conceived early in the program. Scientific information of worldwide interest is appearing in hundreds of journal articles and technical papers. User-oriented publications for forest managers and pest-management specialists are being distributed; at least 38 major handbooks on specialized subjects will be published in USDA series. During the program, technology was transferred through many workshops, seminars, symposia, training sessions, and user-group meetings on specialized subjects.

The CANUSA-sponsored research symposium at Bangor, ME, in September of 1984 was the final technology transfer effort of the joint program. The proceedings of the symposium, "Recent Advances in Spruce budworms Research," published by the Canadian Forestry Service, is both a compilation of the contributions to new knowledge achieved during the program and a



A sixth-instar larva of the western spruce budworm--the life stage that eats the most voraciously--makes short work of these conifer needles.

state-of-knowledge summary of information about the spruce budworms and their effects on spruce-fir forests of North America.

Information and technology provided by CANUSA has influenced how forest managers deal with budworm problems. Eastern forest managers have:

- Reduced acreage sprayed in control programs by applying "targeted harvesting/targeted spraying," using improved aircraft navigation, remote-sensing and photointerpretation, and refined hazard-rating guides.
- Increased dramatically the use of nonchemical insecticides based on Bacillus thuringiensis (B.t.).
- Improved management planning by applying a wood-supply model and a budworm impact study.
- Improved utilization of budworm-threatened and -damaged balsam fir.
- Demonstrated use of an efficient system developed by CANUSA for monitoring moth populations using pheromone-baited traps.

For western forest managers, CANUSA has:

- Provided a package of computer models that allow forest managers to project the effects of defoliation on trees in various age groups over several stand rotations under various management systems.
- Developed more efficient and precise sampling methods for three life stages--eggs, larvae, and pupae.
- Identified major forest zones with different outbreak frequencies and developed methods to predict outbreak frequency.

For forest managers and pest management specialists in the East and West, CANUSA has:

- Developed a variety of methods for hazard-rating forest stands for susceptibility to budworms.
- Provided silvicultural prescriptions to reduce the likelihood of damage in outbreaks.
- Developed, refined, and evaluated an automated egg-mass detector/counter for more efficient population evaluations.

A particularly important achievement of CANUSA was registration of a new strain of Bacillus thuringiensis as a microbial insecticide. Since 1970, the HD-1 strain of B.t. has been in commercial production for use in controlling insect pests. A new strain of B.t. was isolated from spruce budworm larvae by scientists at the Northeastern Station's Center for Biological Control of Northeastern Forest Insects and Diseases, at Hamden, CT. The new strain, called NRD-12, was extensively field tested in the United States and Canada and is now

registered by the Environmental Protection Agency for forestry use, and for vegetable, cotton, and hay crops.

The NRD-12 strain is twice as potent as HD-1 against the spruce budworm and kills the pests almost twice as fast. Speed of kill is very important when foliage protection is the prime consideration.

To meet the objectives of the CANUSA program, scientists at the Pacific Northwest Station developed elaborate population models for western spruce budworm populations to interface with refined models of host-forest stand dynamics. In the course of population studies, the role of birds and ants as predators of all budworm life stages was found to be far more significant than had been assumed, at least at low to moderate budworm densities.

The implications of these findings are important to people managing budworm-susceptible forests in the face of recurring outbreaks over the life of the rotation. CANUSA-sponsored research indicated that silvicultural practices can increase the beneficial effects of birds and ants, and thereby decrease the frequency of outbreaks. The costs of implementing these practices are projected to be significantly less than management of budworm populations with insecticides.

Budworm outbreaks are naturally recurring events in susceptible forests of the United States and Canada. Over the last decade, science has made great strides in understanding these pests and developing rational approaches to dealing with them. Although the CANUSA program has ended, base-funded research to develop safe, effective, and practical strategies for protecting our forests from the spruce budworms will continue.

In the Great Plains, natural tree growth occurs mainly along rivers, streams, and drainage ways. Since the days of the earliest settlements, people inhabiting the region have planted trees to protect soil resources from wind and water erosion, to protect crops and livestock, to beautify the land, and to conserve energy in rural farmsteads. But tree planting in the Great Plains has not always been successful. Many of the tree species planted were poorly adapted to the rigorous climate of the area. Also, pest damage has often curtailed tree establishment. Nearly all the tree and shrub species planted in the Great Plains are susceptible to one or more serious disease and insect pests.

Since the early 1960's, research by Federal and State agencies on diseases affecting trees in shelterbelt plantings in the Great Plains has been greatly accelerated. This increased effort has generated a great deal of information on tree diseases and prompted the pest management committee of the Great Plains Agricultural Council to gather this information into a single document so it would be more useful to landowners, foresters, pathologists, and extension specialists. The result was "Diseases of Trees in the Great Plains," written by 31 contributors from throughout the area and recently published by the Rocky Mountain Station. This handbook describes the hosts, distribution, symptoms and signs, disease cycles, and control measures for 46 hardwood and 15 conifer diseases that commonly damage trees planted in the Great Plains. Effects of environmental stress and damage from herbicides are also covered. Color photographs of the disease symptoms will greatly aid in disease diagnosis.

A healthy two-level windbreak shelters a field of corn in the Great Plains.

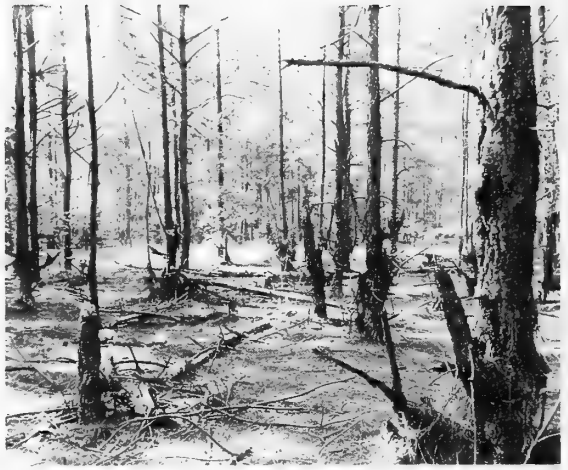
Recently forest scientists have identified a useful supplement to traditional tree-breeding programs. The phenomenon involved is called somaclonal variation. This approach to tree improvement can incorporate desirable traits into forest trees without going through the traditional breeding cycle of 20 to 30 years. The term "somaclonal variation" was proposed to describe variation exhibited by plantlets obtained from aseptic plant tissue cultures. With this technique, it is now possible to take old plant lines and literally turn them into dozens of new plant lines in a matter of months.

Many plants regenerated from aseptic tissue cultures are not true to type. Forest pathologists at the North Central Station have used somaclonal breeding techniques to develop increased resistance to the fungus Septoria musiva in selected hybrid poplar clones. This fungus causes a serious canker disease that limits the productivity of some of the best poplar clones. Approximately 60 days are required from the time a poplar plant is placed into tissue culture until a resistant plant variant is rooted in the greenhouse. In the first 2 years of this study, over 500 somaclones expressing resistance in laboratory tests have been generated. The resistant plants are now being field-tested in Wisconsin prior to release to other workers.

The plantlets in this plastic cup were developed from tissue culture; they are resistant to Septoria wilt.

Fusiform rust, caused by a fungus, is the most serious disease of slash and loblolly pines in the Southern United States. The disease has reached epidemic proportions in many parts of the South, with annual losses estimated at more than $130 million. Because of the economic impact of the disease, an extensive research program has been conducted in recent years by Federal and State agencies, universities, and private companies. Scientists from the Southern and Southeastern Stations and their cooperators have played an important role in this research and have made significant progress in reducing losses from this disease.

The primary emphasis of the overall research program has been on the development of disease-resistant pines. The first breakthrough was finding four geographic areas of loblolly pine where trees exhibit considerable resistance to rust. Seed collected from one of these areas--Livingston Parish, LA--has been widely used in reforestation programs where rust hazard is high. In other research, individual trees of slash and loblolly pines that showed resistance to rust were selected, cloned, and used to establish rust-resistant seed orchards. An artificial inoculation technique was developed that allows rapid evaluation of rust resistance of progeny from individual tree selections in breeding programs. Seedling seed orchards were established using survivors from these inoculation tests. Seed are already being collected from these clonal and seedling seed orchards, and progeny show an improvement in rust resistance of 40 to 50 percent. Until large supplies of resistant seed are available, their deployment will be restricted to areas identified to have high potential for fusiform problems. Such areas are characterized by high populations of oaks, the alternate host of the rust fungus, in or around pine plantations.



These broken and deformed trees in a 14-year-old stand of slash pines in South Carolina are typical of areas with severe fusiform rust infection.

Fusiform rust is a particularly serious problem in tree nurseries. For years the disease has been controlled by the fungicide ferbam, which is applied 35 to 40 times per year. Recently a new systemic fungicide, Bayleton®, was found to

be very effective in controlling the rust. It is now used in almost all nurseries in the Southern United States. This material, which acts as both protectant and eradicant, needs to be applied only three or four times a year.

Much research has been done on influence of various management practices on the incidence and impact of fusiform rust. Intensive cultural practices, such as site preparation and fertilization, tend to increase incidence of fusiform rust. However, increase in volume resulting from such practices may offset even a 50-percent rust infection rate. Thinning has little or no practical value in reducing incidence of rust since most infection occurs in the early stages of stand development. But thinning can affect total wood production in heavily infected stands by utilizing trees certain to die before the final harvest. A preliminary growth and yield prediction model for rust-infected slash pine stands has been developed to help evaluate some of the more common forest-management practices that can reduce losses from this disease.

Slash pine the way it ought to look. This is a seed orchard planted with rust-resistant trees.

Exterior structural timbers can be serviceable for decades with proper care and maintenance. These timbers are usually pressure treated, but deep seasoning checks that penetrate the treated shell can develop. The result is interior decay and premature replacement of timbers at inflationary costs.

Preservatives applied by ordinary flooding from a brush or spray penetrate the wood only slightly and so cannot stop this decay.

Researchers at the Forest Products Laboratory, in cooperation with the U.S. Naval Facilities Engineering Command, have shown that fumigants such as Vapam and chloropicrin, applied to holes drilled in the timbers (for example, curbing) and plugged, can eradicate important fungi that decay wood products. The study also determined the extent and speed of penetration of toxic amounts of fumigants through horizontally oriented timbers as well as the longevity of toxic concentrations of fumes in timbers. Effectiveness of treatments varies, depending on fumigant used and timber species.

The cost to replace decayed timbers has increased out of all proportion to the cost of the raw material. Furthermore, timber has been estimated to increase in value nearly 24 times between the stump and delivery of the finished product. Application of these research findings has potential for high financial return by extending the service life of structures and avoiding costly repairs.

In this schematic diagram, although conventional wood preservatives have penetrated part way into this railroad tie, drying checks have opened up the inner core--past the treated zone--so decay-causing organisms can find their way in. A new fumigation treatment developed at the Forest Products Laboratory will protect wood even in the face of such deep seasoning checks.

Recently the Nordic countries placed an embargo on importation of pine chips and other raw softwood products from the United States after imported chips were found to be infested with the pinewood nematode, which causes the pine wilt disease. Although this disease is minor in the United States, some European pine species are known to be highly susceptible. Curtailing chip exports represents a serious loss to the forest industry.

Researchers at the Southeastern Station are currently studying how the nematode becomes established in pine chips, what influences its survival in chip piles at export terminals, and how it might be eradicated from chips before and during export.

The nematode infests wood through the activities of insect vectors, most commonly the pine sawyers. These beetles colonize pine logs and bolts held in storage yards or standing dead or weakened trees, and introduce the nematode while laying their eggs. The nematodes remain alive after the wood is processed into chips and feed on fungi that colonize the chips.

The survival of the nematodes in chip piles is mainly governed by temperature. Though temperatures near the shell of a chip pile may be lower than in surrounding air, heat near the center of the pile can exceed 60 °C. Optimum temperature for reproduction of the nematode in chips is 35 to 40 °C, but populations rapidly decline above 45 °C. At 60° the nematodes are killed in 1 hour or less; thus none survive in the center of large piles. However, the nematodes do survive in parts of the pile where temperatures are more favorable. Nematodes can also reproduce in ship's holds during ocean crossings since the temperature in the lower part of the cargo hold averages about 35 °C.

It is not economically feasible to use heat to control the nematode because of the limited heat-conductive qualities of wood and the rate at which chips are loaded onto ships. Other methods of control, including fumigation, are currently under study.

Exporting wood chips is big business. Here, a load of southern pine chips (38,000 tons!) is ready for shipment to Sweden.

Wood-destroying beetles cause annual damage amounting to an estimated $50 million in hardwood lumber and secondary manufactured products such as flooring, furniture, millwork, molding, and picture framing. The true powderpost beetles cause the greatest damage because they can infest and reinfest wood after it is dry, reducing it to a dry powder. Losses from termites and decay are much higher.

Current research on integrated protection against beetle infestations by scientists at the Southern Station has yielded effective dip-diffusion procedures using boron compounds to protect moldings made from a Brazilian hardwood (banak) against damage by beetles. In limited commercial use for over 4 years, the borate treatment has generated no complaints about insect, stain fungi, or decay damage to the manufacturer.

Borate dip-diffusion treatments of Latin American hardwood lumber will

Hardwood lumber being treated with borates using the dip-diffusion method.

effectively protect it through fabrication and distribution of the final product. Wood products are immersed for 1 minute in a borate solution and stored under cover for 7 days. Storage permits the borate to thoroughly diffuse through and penetrate the wood. Lumber so treated and moldings made from this treated lumber show excellent protection from damage by powderpost beetles, and considerable protection from damage by termites or brown-rot decay fungi. Adding another fungicidal chemical to the borate solution also prevents discoloration from mold, mildew, and sapstain fungi.

Boron compounds such as boric acid and borax may be used for wood treatment. In wood, borax and other polyborates convert to boric acid, which is toxic to many insects and decay fungi. Though boron treatments are new to the American wood industry, they have been employed in Australia and New Zealand for over 40 years, a testimonial to their usefulness.

Planning the Rejuvenation of Aspen Forests Using Prescribed Fire

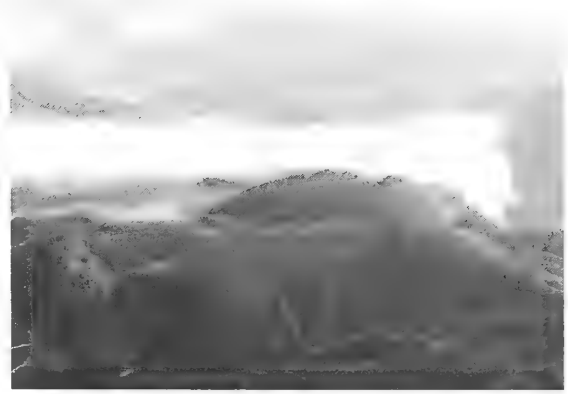
Trembling aspen, a widely distributed forest tree species throughout North America, occupies roughly 7 million acres in the Western United States alone. These forests are especially important for their wildlife, esthetic, recreation, watershed, and forage-production values. Fires have played an important role in developing and maintaining aspen forests, and without periodic fires, the aspen is being replaced by conifers in many areas. This successional process reduces forage production and water yields and diminishes vegetation diversity and the quality of wildlife habitat. Prescribed burning has shown potential as an economically and environmentally acceptable means of reversing this process.

Fire scientists at the Intermountain Fire Sciences Laboratory have developed a method for appraising fuels and flammability in aspen forests to assist in preparing fire prescriptions to promote aspen regeneration. The appraisal process is based on studies of physical fuel properties and vegetation occurring in southeastern Idaho and western Wyoming. It includes a classification of aspen fuels, appraisal of fire behavior potential, and evaluations of seasonal change in live-fuel moisture content. Derived fuel types have been illustrated with color photographs accompanied by information on fuel amounts, vegetation characteristics, fire-behavior ratings, and ratings for the likelihood of burn success. Knowledge of how fine-fuel moisture content, vegetation curing, windspeed, and topographic slope determine fire behavior has been refined to aid in writing effective burn prescriptions for maintaining healthy aspen forests.

In this aspen stand from the Rockies, prescribed fire is used to control unwanted tree and shrub species.

Use of prescribed fire is necessary for good forest-ecosystem management in many parts of the country. In the Pacific Northwest, it is of particular ecological and economic importance. But smoke from forestry-prescribed fires and other open-air burning can cause air-quality problems when too much smoke enters a limited volume of the atmosphere in too short a time. Forestry managers need help to minimize the amount of smoke they generate while accomplishing prescribed-burning objectives.

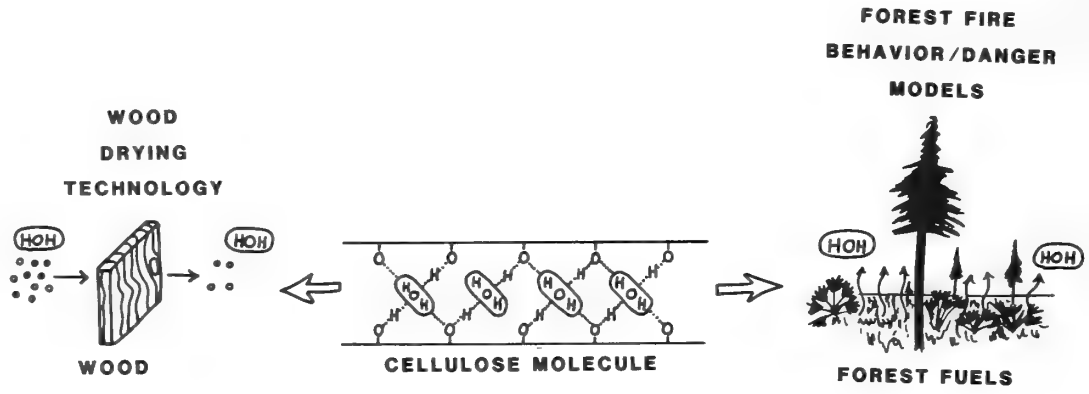
Pacific Northwest Station scientists are helping to assure good air quality and good forest-management practices by gaining basic knowledge of the factors contributing to smoke generation and by turning that knowledge into technology that is being used by foresters. The scientists have combined fire-science theory with extensive field experiments to determine what combinations of harvesting practices and weather conditions produce the least smoke for a given prescribed-burning objective. They have used this hard-won knowledge to develop a new smoke-management and emissions inventory system. The new system includes such factors as size of logging residue materials, terrain slope, time since rainfall, temperature, wind, humidity, and other weather data. Smoke amounts can vary by more than 50 percent, depending on the variables involved. All forests in the Forest Service's Pacific Northwest Region and the State of Oregon Department of Forestry have adopted the new system for use.



Prescribed burning is an important forestry tool, but for it to remain useful, we must be able to prove that the amount of smoke generated is manageable. Studies in Oregon and Washington reveal that burning in springlike weather results in less smoke.

People often ask why live, green trees and other vegetation burn in forest fires, and why those fires can be so dangerous. When they witness actual forest fires, they are often amazed by how rapidly living trees can ignite and how intensely they can burn. To understand why living trees ignite and burn, we must also understand the role of dead forest materials. Scientists have found that the moisture content of dead leaves, twigs, and branches is an important factor influencing the danger and behavior of forest fires. When sufficiently dry, these fuel materials can often burn fiercely enough to dry out and ignite the moist, living vegetation surrounding them. The result is explosive and potentially dangerous fire behavior.

How do these dead forest materials actually dry out? Although researchers have been studying the moisture relationships of these materials for some time, they have not attained a full understanding of forest drying mechanisms. Results of basic Forest Service research are providing new insights into the wood drying process. Our findings provide a fascinating view into the microscopic world of cellulose molecules and how moisture enters and leaves that world. These studies on the sorption of water vapor by cellulose materials can be applied to treated lumber as well as to dead forest materials. The basic insights gained have been applied in the development of a mathematical model describing temperature and moisture changes of common southern forest fuels as they respond to changing air temperature and relative humidity. Results of this research are being incorporated into a new generation of fire danger-rating and fire behavior-prediction models.

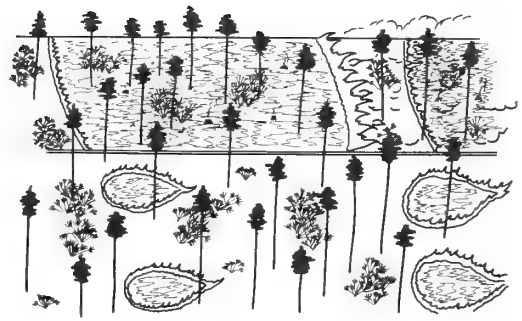


HOW DOES MOISTURE MOVE IN AND OUT OF WOOD AND FOREST FUELS ?

Though visitors know that forests are living, many would be surprised to learn that the microscopic movement of moisture in dead forest materials helps to determine how forest fires start and spread--and whether the forest will continue to live well.

To grow competitively priced timber in the Southeast, forest managers rely heavily on the use of prescribed fire as a silviculture treatment technique. To be cost effective, prescribed fires must be ignited in numbers over large acreages during intervals when weather conditions, combined with burning techniques, will produce the desired treatment results within budget. The large, and often dispersed, acreages involved suggest that airborne ignition is the best way of getting the job done. However, these ignition techniques must work well for airborne delivery, must meet the ignition patterns required for the silvicultural objectives, and must be inexpensive.

After several years of research, our scientists have perfected methods for airborne prescribed fire ignition. Two techniques have been shown to be particularly effective--the helitorch and the Ping-Pong ball system. Of equal importance are the research results that demonstrate that each technique is favored for different sets of desired burning objectives and for different types of aircraft. As the name would suggest, the helitorch is particularly applicable to helicopter delivery; the Ping-Pong technique works well with fixed-wing aircraft. Burns started with a helitorch have higher fireline intensities than those ignited using the Ping-Pong ball system. The completed research shows that conclusions drawn are valid for all southeastern combinations of fuel and weather.



The helitorch and Ping-Pong systems provide two tested methods for igniting the prescribed fires that are heavily used in the South for silviculture treatments.

When veteran firefighters talk about the worst forest fires they have faced, when rookie firefighters are warned about dangerous situations they may encounter, and when fire researchers describe the most challenging problems they must solve, crown fires are at the top of all three lists. Crown fires involve the active burning of the upper portion, or crown, of forest vegetation. No matter what species is burning, crown fires are intense and fed by the most volatile part of the plants involved.

Forest Service fire scientists have made remarkable progress in developing computer models that predict the behavior of wildfires. These model predictions are used onsite by fire managers to employ their resources in the most efficient ways. But today's operational fire-behavior models are not capable of accurately predicting

Schematic diagram of a computer simulation showing the relationship between heat generated by a fire (vertical axis) and the degree to which trees in advance of the fire front are nearing ignition, over distance (horizontal axis).

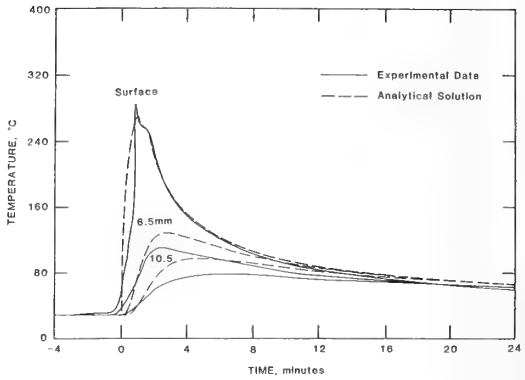
the behavior of crown fires, the most destructive type of wildland fire. Intermountain Station scientists have embarked on a systematic research attack to produce the needed fire-behavior predictions of crown fires. Their approach is to develop a series of mathematical models that will evolve over the next several years into a definitive predictive system for crown-fire behavior. Initial progress has been made by modeling the spread of a line fire through wildland fuel for situations in which unignited vegetation is heated by radiation and cooled by reradiation and convection. Success in depicting the complex physics of crown fires with this initial modeling attempt demonstrates that the scientists are off to a good start in their planned approach to solving the problem of predicting the behavior of these most destructive forest fires.

Soil heating caused by wildfires and prescribed burns plays a large role in determining the effects of fires on wildland resources. The intensity, depth, and duration of soil heating affect soil stability and fertility as well as subsequent vegetation responses. The ability to understand and predict these responses is a critical prerequisite for effective prescribed-burning programs.

Scientists at the Pacific Southwest Station have studied ground surface heating both analytically and experimentally to develop new information on the relationships of flame and soil characteristics to soil temperatures. Results of these studies have provided a predictive mathematical model of heat transfer to soils. The important heat transfer processes identified are conduction of heat into the soil; radiant exchange between the flame, soil, and surroundings; and radiant exchange between the soil, surface, and smoldering embers left behind the flame front. Important fire characteristics that drive these processes include the duration of burning at a single location, and the geometry and temperatures of flame and embers.

Results indicate that the location of maximum surface temperature depends only on the flame characteristics, but the magnitude of the surface temperature depends on properties of both the flame and the soil. Actual measurements of soil temperature during experimental burns agree well with the model's predictions.

Use of the soil heating model will improve the effectiveness of prescribed burning as a means of managing wildland vegetation. It is especially applicable in the highly flammable chaparral communities of southern California.



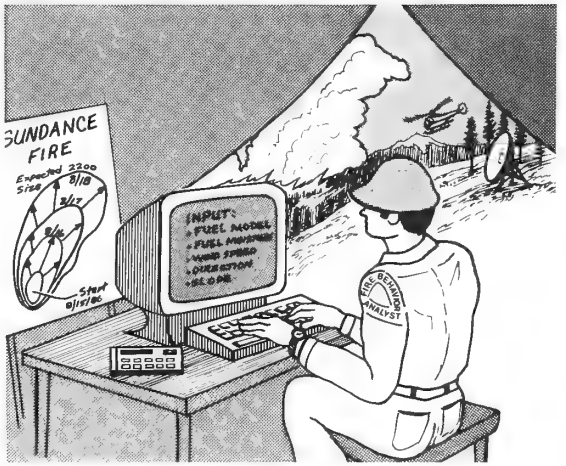
Damage to soil and soil microorganisms from forest fire heat can now be better predicted by mathematical models. Experimental data verified the analytical mathematical solutions as shown here.

Research on fire weather, wildland fuel characteristics, and fire behavior has provided an array of operational systems and decision aids for fire-management personnel. Their jobs include (1) prepositioning firefighting forces and equipment on a national and regional scale, (2) designing fire-management organizations to meet local needs, and (3) devising fire-suppression tactics on individual fires. Two automated fire behavior/weather-related systems are especially noteworthy: the National Fire Danger Rating System and BEHAVE.

The National Fire Danger Rating System was designed to track relative trends in fire danger over broad geographic areas. This system uses local weather observations and forecasts with information about wildland fuel flammability to produce indices of expected wildfire occurrence and behavior. The system is used to preposition firefighting resources and plan fire-management activities by all Federal land-management agencies and more than 30 State and private wildland fire-protection agencies.

BEHAVE, a system of interactive computer programs to aid in predicting fire behavior, is used in deploying initial attack forces to actual fires. It also makes real-time projections of a fire's perimeter to help managers make suppression decisions. Finally, BEHAVE assists managers in developing strategies and tactics for the controlled use of fire to attain specific management objectives.

Operational use of BEHAVE during the 1985 fire season was credited with saving millions of dollars in suppression costs, structural losses, and forest resource damages--as well as human lives. The Forest Service projects combined cost savings attributable to these two research products of $3 million to $10 million annually, depending on severity of the fire season.



Estimating the progress of wildfires is much more accurate thanks to computer programs that factor in topographic weather and fuel data.

Reliable predictions of wildland fire behavior are needed for a wide range of fire- and resource-management tasks. These predictions are useful not only for more effective suppression of wildfires but also for improving the cost, safety, and success of fire use and for determining the long-term growth and effects of natural fires allowed to burn in remote areas. Twenty years of continuing Forest Service research on the behavior of free-burning fires in wildland fuels has produced a basic understanding of surface fire phenomenology. The process by which a surface fire spreads can be visualized as a series of ignitions of the particles of fuel that are burned at or near the fire's leading edge.

By a combination of theoretical development and laboratory experimentation, scientists at the Intermountain Fire Sciences Laboratory have provided quantitative knowledge of surface-fire behavior that is especially applicable when a steady-state, line-fire is spreading in a spatially uniform fuelbed at ground level. (The vast majority of forest and range fires burn under these conditions.) The research results have provided the predictive basis for an array of operational fire systems and decision aids. Ongoing research will concentrate on extending fire behavior knowledge to less frequent but more complex fire-management situations involving spotting, crown fire development, and multilayer or nonuniform fuelbeds.

Experiments at the Intermountain Fire Sciences Laboratory have told us a great deal about how steady-state line fires spread at ground level--the burning conditions for most forest and range fires.

Increasing Success of Forest Regeneration Through Better Ecological Knowledge

Forests of the northern Rocky Mountain and Intermountain areas are characterized by a wide diversity of site conditions. Research-based knowledge of specific sites and their ecological properties and processes can make it possible to greatly reduce losses and failures in both natural and artificial forest regeneration.

More than 10 years of forest ecology studies have resulted in keys to coniferous forest habitat types for northern, central, and eastern Idaho and all of Montana and Utah. Similar work has been done for the aspen forests of Utah, southeastern Idaho, western Wyoming, and Nevada. More recent work, some still underway, has provided keys to ecological processes and stages for the most important timber-producing forest habitat types.

Habitat type classification provides a system for predicting the potential vegetation on a given site. The large, widely scattered ponderosa pines illustrated in the figure will be replaced by a dense stand of Douglas-fir, and the sward of grass will be replaced by low-growing shrubs. Prescribed burning and timber harvest patterns can be used to alter the successional trend so as to maximize resource values.

Several handbooks have been prepared for field silviculturists. Four General Technical Reports have been issued, and training sessions are held annually. This work has been a result of close cooperation between Forest Service Research and the National Forest System's Northern and Intermountain Regions.

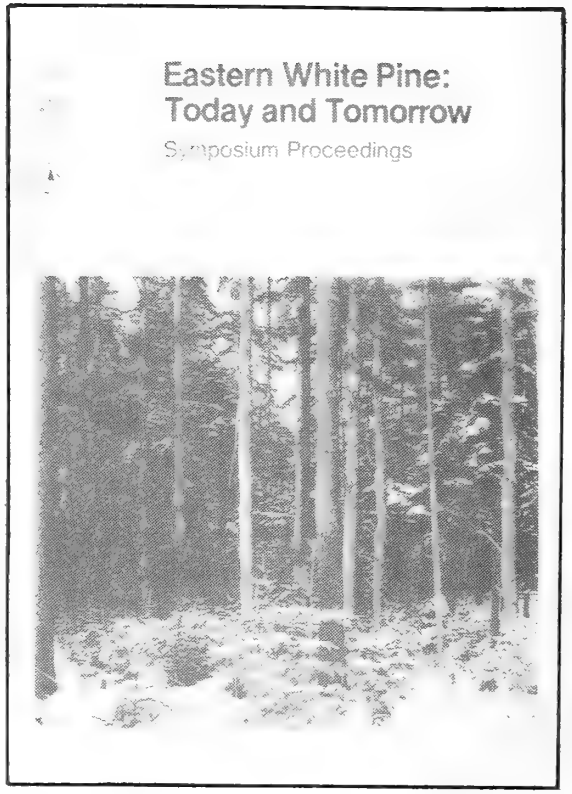
The striped stick is part of an inconspicuous monitoring device.

Although white pine was the premier species logged to build ships and houses for almost 300 years, it now accounts for less than 1 percent of all softwood timber removals, and only half the species' annual growth is cut yearly. Opportunities exist, however, for managing white pine to enhance log quality, volume, and value. To provide an update on such opportunities, as well as current information on the white pine resource base, protection, marketing, and wildlife amenities, a symposium was held in Durham, NH, in June of 1985. The University of New Hampshire, the Society of American Foresters, and the Ruth E. Farrington Fund joined the Forest Service in sponsoring the meeting and publishing the proceedings.

Although white pine occurs in pure stands, most of it grows in mixture with other eastern species. Landowners generally try to favor white pine by controlling competition from less valuable hardwood species. Pure stands can be regenerated very successfully by planting white pine. Growing this species for timber production also provides wildlife habitat and enhances woodland esthetics.

The primary impact of white pine weevil damage is reduced wood quality, whereas blister rust infection often results in tree mortality. Not all stands are attacked, however, and both problems are less severe in the southern part of the white pine range. Managers can make better use of knowledge about blister rust incidence zones in selecting plantation sites, and chemicals can control the weevil. But there is still a need to develop strains of eastern white pine that have genetic resistance to the rust and to weeviling.

Now used primarily for finish carpentry and furniture, select-grade white pine lumber commands prices five times as high as industrial-grade white pine, which is often used for shipping pallets and boxes. Considerable opportunity exists for manufacturing logs to grade, thus adding 200 percent to their value through drying, dressing, and grading. Careful cutting in the woods can maximize the number of clear logs and group defects in other logs.



Guidelines for forest managers and silviculturists overseeing spruce-fir forests in the central and southern Rocky Mountains, and Front Range ponderosa pine and lodgepole pine in the central Rocky Mountains are now available as three reports from the Rocky Mountain Station. The reports offer suggestions on developing even- and/or uneven-aged cutting practices for converting old- and mixed-growth stands into managed stands for a variety of resource needs.

Guidelines consider stand conditions, succession, windfall risk, and insect and disease susceptibility. Suggested cutting practices are designed to integrate timber production with increased water yield, maintained water quality, improved wildlife habitat, and enhanced opportunities for recreation and scenic values.

No one silvicultural system or cutting method meets all resource needs. Cutting small openings provides maximum yields of timber at minimum costs, promotes the largest increases in water production without serious reduction in quality, produces diversity in food supply and cover favored by many wildlife species, and is compatible with the development of ski trails and homesites. Shelterwood cuts also provide maximum timber yields over the same time interval, but at increased costs; they produce a wide range of wildlife habitats, but with less forage than openings and less cover than uncut forests. After shelterwood cutting, water yields are increased over natural streamflow but less than with clearcutting small openings. Shelterwood cutting provides a partial retention of the forest landscape, but only when the overstory is retained for a long time. Group selection and shelterwood cutting methods impact the same resource values as patch or strip clearcuts, but the former are more complex and expensive to implement.

Not all resource needs can be met on a given site, nor is any one cutting method compatible with all uses. Land managers must recognize the potential multiple-use values of each area, determine the primary and secondary uses, and then select the management alternative that is most likely to enhance or protect these values. On an individual site, some uses must be sacrificed or diminished to maintain the quantity and quality of others.

Fairly large patch cuts (3 acres) in lodgepole pine benefit water yield and wildlife habitat while enabling owners to realize income from their forest land without damaging the environment.

To ensure that oaks will replace themselves after cutting, managers must make sure that advanced oak reproduction is already established on the forest floor at harvest time. But on sites in the southern Appalachians that are capable of producing high-quality sawlogs, large advanced reproduction of northern red oak does not develop until the stand is disturbed (such as by thinning or wildfire). Similarly, forest managers in the Central States often find that oak advanced reproduction is inadequate to regenerate oak stands on high-quality sites.

Research conducted by the Southeastern Station on the Bent Creek Experimental Forest in North Carolina and the Chattahoochee National Forest in north Georgia over the past 10 years indicates that basal area reductions of up to 40 percent in mature stands lead to better growth of established red oak seedlings, without the simultaneous development of species that can outgrow red oak after overstory removal. The basal area reduction should be done from below using herbicides, leaving the main canopy largely intact. Final harvesting of crop trees can be made 10 to 15 years after this initial treatment. The large released oak seedlings then successfully compete with seedlings of other shade-intolerant species, and the herbicide treatment leaves few stump sprouts of tolerant understory species.

Researchers at the North Central Station in Columbia, MO, also advise forest managers on how to successfully regenerate northern red oak in the Central States by underplanting within stands before final harvest. The four-step prescription is to (1) create a shelterwood of medium density during harvest of the current oak stand, (2) control unwanted woody vegetation with a herbicide, (3) underplant large transplants or undercut nursery stock with clipped tops, and (4) remove the shelterwood three growing seasons after planting.

There is plenty of advanced reproduction of northern red oak in this stand, which was treated with herbicides 9 years ago. When the overstory is harvested, these 10-foot trees will take over. Without early herbicide intervention, other less desirable species would dominate in the absence of red oak seed trees.

Forest resource assessments and vegetation maps have been completed for the territories of Guam and American Samoa, the Federated States of Micronesia, and the Republic of Palau. With the aid of this area and volumetric information and the type maps, the islanders will be better prepared to manage their scarce natural resources. Imagine how difficult it has been for the Pacific people to develop plans without quantitative knowledge of the extent, location, and composition of their resources. The surveys and inventories were conducted jointly by forest assessment specialists from the Pacific Southwest and the Pacific Northwest Stations. Support was provided by the island forestry agencies and Peace Corps volunteers.

The people on the high island of Yap are considered to form the most conservative society in the Caroline Islands. Yet they have developed the most productive agroforestry system in Micronesia. A Pacific Southwest Station biologist is examining the species composition and productivity of this island's agroforests. Opportunities to supplement the islanders' diets through the introduction of superior multiple-use trees are being examined. Advanced agroforestry practices developed on Yap could readily be transferred to the many similar islands in the Pacific.

The low coral atolls in the Marshall Islands support relatively few food plants and tree species. The Pacific Southwest Station is conducting fertilizer trials for agroforest species on Majuro. These trials revealed that small amounts of a complete fertilizer greatly increase growth and yields. At the request of the government of the Marshall Islands, the Pacific Southwest Station is conducting species and fertilizer trials on the overpopulated atoll of Ebeye. This research is part of that government's efforts to establish windbreaks and create amenity plantings.

At the request of the government of the Marshall Islands, the Pacific Southwest Station is conducting species and fertilizer trials on the overpopulated atoll of Ebeye. This research is part of that government's efforts to establish windbreaks and create amenity plantings. Fertilizing can make a big difference; a treated coconut palm is on the right, an untreated tree on the left.

The Institute of Tropical Forestry, part of the Southern Forest Experiment Station, recently completed a 3-year study of five eastern Caribbean islands for the U.S. Agency for International Development. Part of the U.S. Government's contribution to the Caribbean Environmental Action Plan, the five-phase study provided quantitative assessments of the state of natural resources in the Caribbean islands, trained young people in the management of these resources, and provided guidelines for such management using principles oriented toward maximizing vegetation cover and sustaining resource use.

Each of these phases produced important results with implications to island development. For example, 24 Caribbean foresters representing seven islands received training in tropical forestry. Many of these young men and women have advanced in position and responsibility in their respective forest services and continue to communicate with the Institute on technical matters. The wildlife assessments were conducted on nine islands and involved many additional activities, such as seminars, consultations with local authorities, and interviews for use in mass communication media. Habitat destruction was found to be the most severe threat to the wildlife of these islands.

Watershed studies produced 3 years of continuous information (taken at 15-minute intervals) on rainfall and stream discharge of three major watersheds on three islands. Sediment and water-quality data were also collected and used to develop predictive equations of watershed behavior. This work was conducted in cooperation with the U.S. Geological Survey and is the first such study in the eastern Caribbean. Data are being used for planning of water-development projects, and island governments want to continue the program.

Prescriptions for forest management with the goal of minimizing hurricane damage to trees were developed from detailed assessments of damage of hurricanes to plantations and natural forests in three islands. Hurricane damage was pervasive islandwide. In addition, the first comprehensive forest survey of Saint Vincent revealed that about 38 percent of the island is forested. The need to protect native stands on steep areas was highlighted in the recommendations.

Results were transferred throughout the region in the form of five major publications and in meetings of Caribbean foresters. The synthesis of this study, which focuses on environment and development, was presented at a global conference on island development sponsored by the United Nations' Man and the Biosphere Program in Puerto Rico in October of 1986.

Students from various Caribbean islands during their 3-month forestry course at the Southern Station's Institute of Tropical Forestry. Their mentor, Station scientist Ariel Lugo, is in the second row, to the left of the "T" in "Tropical."

Over the years, Forest Service researchers and their colleagues in the university and forest-industry sectors have developed extensive information on the silviculture and management of Appalachian hardwoods. Much of this information was recently summarized for field foresters and landowners during a workshop entitled "Guidelines for Managing Immature Appalachian Hardwood Stands" and in the accompanying proceedings.

Speakers presented "how-to" guidelines based on the literature and their knowledge and experience. They made recommendations on how to manage sapling, pole, and small-sawtimber stands and discussed the role of past history on present stand composition, the benefits of quality timber products, market trends, and coordination of wildlife- and timber-management practices.

Researchers recommended that Allegheny hardwood stands be thinned to maintain 60- to 80-percent relative density, with emphasis on removing poor-quality trees. Another presentation focused on Appalachian cove hardwood stands that will produce large, high-quality timber with minimal silvicultural treatment. Even in these productive stands, initial thinnings when stand height is about 50 feet and perhaps subsequent thinnings every 10 to 20 years will concentrate growth on high-value trees and shorten rotations by 30 to 50 percent.

The workshop was sponsored by West Virginia University and the Northeastern Station, in cooperation with the Allegheny Society of American Foresters. There is a major market for this research, as evidenced by the fact that over 300 people, from 43 organizations and 15 States, attended the workshop.

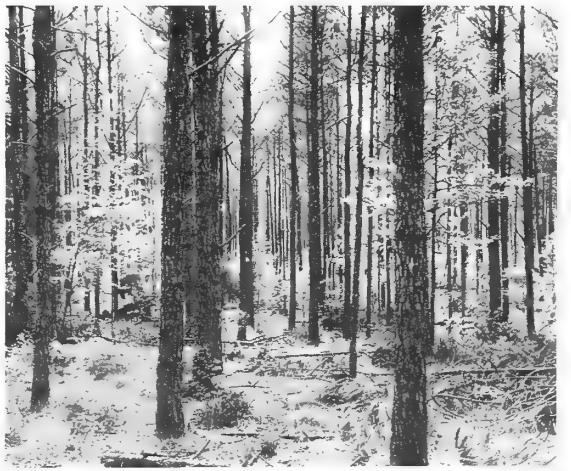
Removing larger hardwoods gives the remaining trees a bigger share of nutrients and sunlight, thus promoting faster growth in this healthy stand.

Maintaining or improving the productivity of the land is part of the forestry ethic. In the long rotations of traditional forestry, obtaining adequate reproduction after harvests satisfied management's concerns for the future. Now with short rotations and chipping of entire trees, including foliage, soil nutrients may be taken away faster than they have ever been taken before in well-managed forests. To manage this possible long-term decline in site productivity, a forester must have some understanding of nutrient cycling--the movement of nutrients into, within, and out of forest ecosystems. A new guide, "Foresters' Primer in Nutrient Cycling," provides the sort of information a forest manager needs. It tells the concentrations of nitrogen, phosphorus, and potassium found in various tree parts as the trees age. It gives the quantities of nutrients that accumulate in the forest beneath loblolly pine and the quantities that break down and pass to mineral soil. It also estimates the nutrient losses associated with prescribed burning and other forms of site preparation.

As forest treatments go, fertilizer application is fairly expensive--too expensive to do without assurance of a positive result. The new management guide "When and Where To Apply Fertilizer" tells forest managers about using foliar analysis to determine fertilizer applications, the levels of phosphorus to add to most soils, the greater response to nitrogen on sites where it is limiting but moisture conditions are favorable, and the expected returns of 10 to 28 percent for fertilizer applications on some sites.

On poorly drained, heavy soils, logging can destroy soil structure, block drainage, injure seedlings, and remove valuable nutrients. On Coastal Plain sites, as much as two-thirds of a logged area can be damaged, and costs in lost productivity can be $60 to $90 per acre, according to the guide "Managing Site Damage from Logging." Historically, the blame for this damage has been placed on the logging contractor, but much of it can be prevented by careful timber-sale planning, preparing the site for logging, and careful supervision during the logging.

In all, five "pocket guides" have been published to update forest managers on years of research conducted by scientists participating in the Loblolly Pine Management program in the Southeast. They offer advice on applying fertilizer, nutrient cycling, and managing site damage from logging. In 1987, guides on site preparation and southern seed sources will be printed as part of the Forest Service's commitment to sharing its research results with users.



A handsome and healthy stand of planted loblolly pine (6- by 6-foot spacing) in Louisiana's Alexander State Forest. The photo was taken after the initial thinning, at stand age 25.

In the last two decades, Forest Service research has developed timber growth-and-yield models that can be used to describe the present forest and predict its response to change resulting from human activities and natural events. Using these computer models, an inventory of the forest, and a "what if" approach to the decisionmaking process, forest land managers can relate alternative forest-management strategies to yield of forest products.

Enhancements to these growth and yield simulators include computer programs that consider (1) the impacts of insects and diseases on forest development, (2) genetic gain information for estimating increased production resulting from improved planting stock, and (3) evaluation of regeneration prescriptions; and tie the growth of trees to wildlife habitat and watershed protection concerns.

The usefulness of these highly sophisticated computer models is being reinforced through the addition of economic options that allow the user to look at costs and revenues at the same time that forest-management alternatives are being simulated.

Computer programs for these models and supporting user's guides for many of the major hardwood and conifer forest types of North America are available from the forest experiment stations. Although many of these models require a large computer, several have versions or were developed specifically for personal computers.

Sufficient seed supplies are critical to reforestation. Research in the Southern Station has shown that seed production can be greatly increased by locating pine seed orchards in warmer climates. Problems with reproductive phenology, however, may limit transfer into subtropical climates. Research is continuing on whether "after effects" of the seed-production climate persist after seedlings are planted in cooler locations. The photograph shows an abundant cone crop harvested from a grafted Virginia pine tree planted in south Mississippi (450 miles southwest of its origin). This seed will be planted at more northern sites, and seedling progress will be closely monitored.

As increasing quantities of genetically improved seed are available from seed orchards, forest managers need to make informed decisions about deploying this material. The challenge is to maintain genetic diversity in commercial forests while at the same time seizing opportunities for greater yields through the use of genetically improved stock.

If seeds harvested from seed orchards are collected by family and sown separately in the nursery, forest managers can plant stands with mixtures of desirable genotypes, on the basis of fiber-yield capacity or other traits of interest to the manager. By varying the timing and spatial patterns of genetic groups, almost any pattern of genetic diversity could be achieved with either pure or mixed stands. Also, different management regimes can be tailored to match the requirements of the planted genetic material.

This Virginia pine produced a substantial cone crop despite being planted in southern Mississippi, 450 miles southwest of its origin.

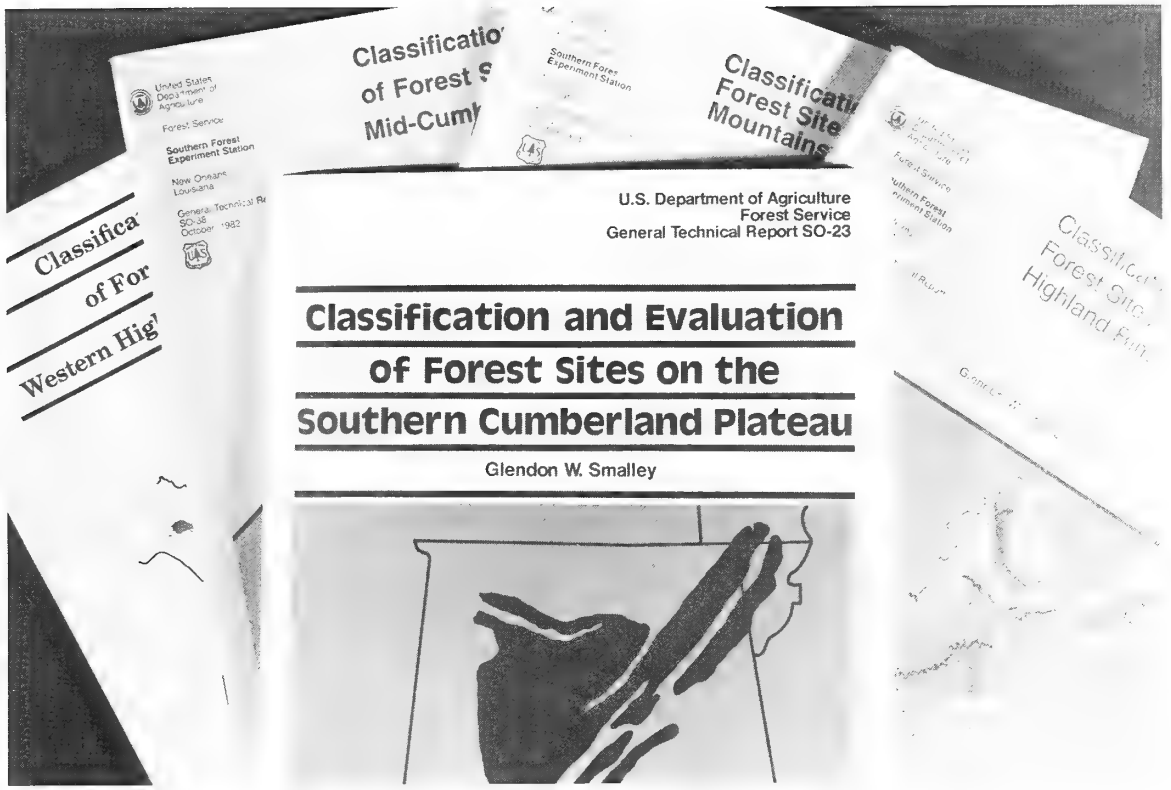
Because forest managers are faced with the challenge of producing more wood on a diminishing acreage of commercial forest land, the need for site-classification and productivity information is a high priority. This need has been met for the interior uplands in the Southeastern United States. A scientist at the Southern Station's silviculture laboratory in Sewanee, TN, has developed a comprehensive but practical forest site-classification and evaluation system. Geographically, the system covers the Cumberland Plateau and Highland Rim-Pennyroyal physiographic provinces (about 29 million acres) in parts of five States (Alabama, Georgia, Tennessee, Kentucky, and Virginia). Six regional guides have been published, and several articles have been written describing the rationale and methodology involved.

The uplands, like the entire eastern hardwood forest region, has a long history of indiscriminate cutting, burning, grazing, and clearing for agriculture. On the average, productivity is far below potential because of poor stocking, an undesirable mix of species, and the presence of defective and low-vigor trees. Consequently, in the development of the system, vegetation was relegated to a position of minor importance.

The hierarchical system, which is based primarily on geomorphology and soils, can best be described as a process of successive stratifications of the landscape: physiographic province, region, subregion, landtype association, and landtype. Nearly 200 landtypes have been defined in the six regional guides.

In the published guides, each landtype is described in terms of nine elements--geographic setting, dominant soils, bedrock, depth to bedrock, surface soil texture, internal soil drainage, relative soil water supply, soil fertility, and vegetation. Each landtype is evaluated in terms of productivity and desirability of selected hardwoods and conifers for timber production. Also, each landtype is rated for five soil-related problems that can affect management operations--plant competition, seedling mortality, equipment limitations, erosion hazard, and windthrow hazard.

An intensive study of the chemical and physical soil properties on three major landtypes on the mid-Cumberland Plateau showed that the system separates the landscape into units with relatively homogeneous soil properties and potential timber productivity. Use of the system for evaluating wildlife habitat is currently being studied.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Forest Service researchers at Rhinelander, WI, Olympia, WA, and Honolulu, HI, are developing methods for farming fast-growing trees using agronomic practices common to corn or wheat production. Trees are grown at close spacing, usually with intensive weed control, fertilization, and irrigation. If the demand for wood increases and supplies become short, land managers will have this alternative system to grow large supplies of wood near plant locations, for fiber, fuel, and wood products.

Field trials in Rhinelander have shown that wood production can be increased three to five times over that of a natural forest, and that yields of 15 tons per hectare per year--equivalent to 43 barrels of oil--can be attained. Scientists have developed new silvicultural systems for establishing and managing fast-growing plantations of hybrid poplar, including cultivation for weed control, as illustrated in the figure. They have also shown that rapidly grown, intensively cultured wood is suitable for reconstituted products such as kraft paper and structural particleboard. Poplar foliage can be used for animal feed. Although growing trees rapidly requires considerable energy input, it pays in terms of energy production: for every unit of energy input in the northern Wisconsin tests, there are 10 units of energy produced in harvested and chipped wood.

Short-rotation forestry trials in Oregon and Washington are focused on developing cultural practices for red alder and hybrid poplar, evaluating and exploiting genetic variation, and predicting site productivity. Spacing trials in red alder plantations throughout the Northwest are generating information on the effects of five planting densities on mortality, individual tree growth, and biomass production per hectare.

Because of their quick growth and high yields, Eucalyptus saligna and E. grandis species are especially favored for wood, fiber, and fuel production in Hawaii. They have been planted extensively in a cooperative venture by the BioEnergy Development Corporation, the Forest Service, and the Department of Energy. In field trials evaluating the effects of stand density, fertilizer, weed control, and seed sources, biomass yields have exceeded 25 dry tons per hectare per year on most average sites. To compensate for nitrogen deficiencies in most soils, two leguminous tree species of the Acacia and Albizia families were planted in mixtures with eucalyptus along the Hamakua coast, on the island of Hawaii. After five and a half years, crop yields averaged 38 tons per hectare in pure eucalyptus, 52 in eucalyptus with Acacia, and 95 in eucalyptus with Albizia, demonstrating the potential for interplanting leguminous trees with eucalyptus.

The machine digs the hole for the new tree seedling, the men drop the containerized seedlings into the hole and tamp them down with their feet, and the machine waters the seedlings before moving forward in the row. This system combines the best of both machine and hand planting.

The first commercially important foreign gene has been genetically engineered into a forest tree. In cooperative research, scientists from the University of Wisconsin, Calgene, Inc., and North Central Station used the bacterium Agrobacterium to insert an herbicide tolerance gene into a hybrid poplar. The gene, which confers tolerance to the Monsanto herbicide Roundup®, was isolated from the bacterium Salmonella by Calgene scientists. The hybrid poplar that contains this new gene has exhibited increased but not complete tolerance to sprays of the herbicide in initial greenhouse tests. Poplar totally tolerant to herbicides would be excellent for intensive forestry plantations, where weed control using chemicals is difficult to achieve without killing the crop trees.

Biotechnology techniques are of even greater potential benefit in forestry than in agriculture because traditional approaches to plant breeding require a disproportionately longer time in large, long-lived forest trees than in agronomic crops. The Forest Service has taken the lead in the application of this new technology to the genetic improvement of woody plants. But until now, opportunities for forest scientists to develop a working knowledge of biotechnology have been limited. To meet this need, the Institute of Forest Genetics gave an intensive 4-week course in biotechnology to promote the use of recombinant DNA, tissue culture, and isozyme technologies in forestry. Designed for senior scientists from university, government, and industrial research organizations, the new course was invaluable in quickly moving molecular and cellular technologies into forestry, building an interactive network of forest scientists, and multiplying the Forest Service effort manyfold.

The genetically engineered hybrid poplar clone on the right is much more robust than its control partner.

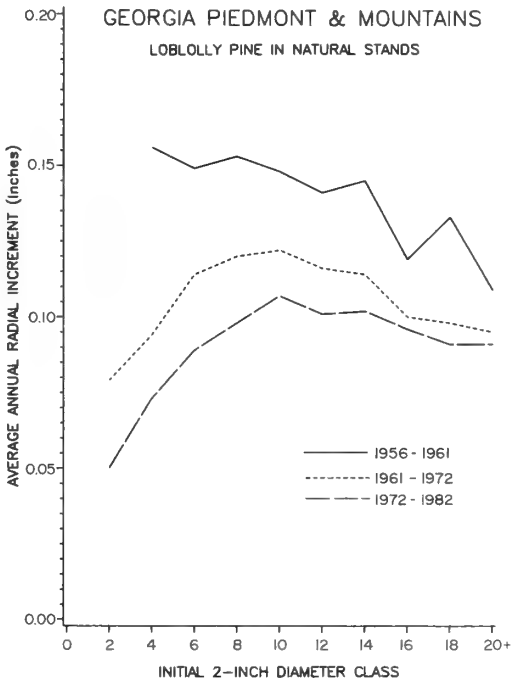
Southern Pine Growth Decline in the Southeast

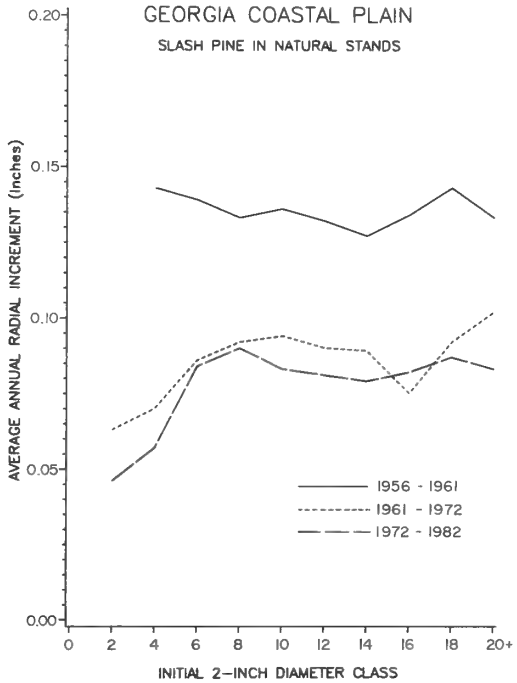
Periodic timber inventories at the Southeastern Station show that net annual growth of pine in the Atlantic Coast States from Virginia to Florida has peaked and turned downward after many years of increase. We knew that three factors--inadequate pine regeneration, fewer acres of timberland, and increased pine mortality--have contributed to this reduction in pine volume growth. In addition, during a comprehensive analysis of pine growth over the past three decades, we discovered that growth rates for natural pine trees and stands had declined.

The study shows that average annual radial growth of yellow pines under 16 inches in diameter has declined by 30 to 50 percent over the past 30 years. Lower rates of individual tree growth have translated into reduced stand-level growth. In the Coastal Plain, much of the reduction in growth rate appears to have occurred in the 1960's, followed by more stable growth patterns. In the Piedmont plateau, declines are evident throughout the past two to three decades.

Average stand age and density have been increasing in the Southeast, and these changes probably have contributed to the declines in growth. Analyses indicate, however, that these factors do not explain a majority of the decline. Other possible causes include drought, atmospheric pollution, an increase in hardwood competition, and a loss of old-field conditions, or perhaps some combination of these factors. The Forest Service is continuing to investigate the reason or reasons for these growth declines in natural pine stands.

Both loblolly and slash pines grew more slowly in Georgia during the 1972-82 period than in prior decades. Researchers have not yet determined why, but several studies are underway to evaluate the situation.

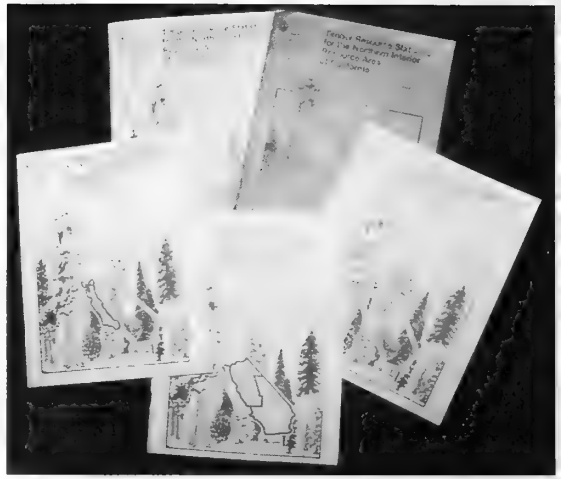




The latest California forest resource inventory, as published in five Forest Service resource bulletins, shows that the volume of hardwoods has increased since the last inventory and the area of hardwood timberlands (closed forests) has increased, while the area of hardwood woodlands (open forests) has decreased. This information proved timely since the California Board of Forestry designated a special task force to study the hardwood situation. Currently, the State's forest practice law applies only to timberlands. The Board is assessing the question of whether or not woodland areas should be regulated.

New statistics for the North Coast Resource Area, the most important timber-producing region of the State, showed that hardwood volume has increased an average of 2.65 percent annually since the previous inventory, while conifer volume decreased 1.35 percent annually. Acreage in hardwood types has increased commensurately, occupying about 800,000 acres that formerly supported Douglas-fir and redwood. Comparative statistics showed that while conifer volume declined, the total number of conifer trees increased by 55 percent and the condition of timberland improved in terms of future stand productivity. Poorly stocked areas decreased from 22 percent of total forest area to only 5 percent, and conifer growth rates increased.

While hardwoods on timberland have increased, the area of hardwood woodland has decreased, and some hardwood species--blue oak and valley oak especially--seem to be declining. Range clearing, urban expansion, and road and reservoir construction have eliminated over a million acres of hardwood woodland since 1945. In addition, regeneration of oaks is not keeping up with natural mortality in the remaining woodland areas. Woodland is gradually phasing into nonforest in many parts of the State. Some observers believe firewood cutting is speeding up the decline of



California oaks and grazing is a factor in poor oak regeneration.

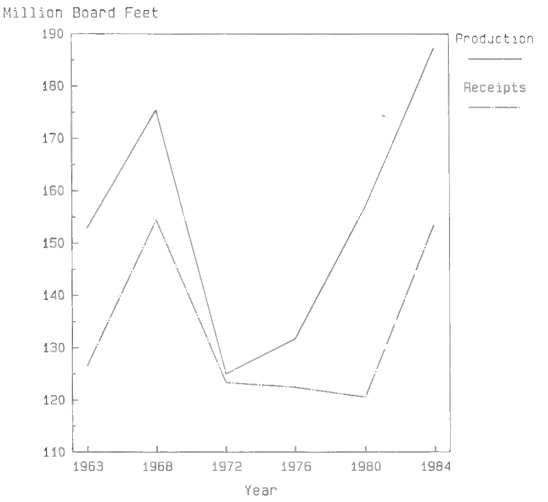
This current resource information was included in a jointly written report to the California Board of Forestry and will be essential to their deliberations. In addition, it will be entered into the California Department of Forestry's geographic information system and used in several ongoing analytical models.

Production and Consumption of Veneer Logs Continue To Rise

To make appropriate decisions about harvesting and replanting, timberland managers need up-to-date statistics on how much northeastern timber is being used for industrial forest products. Periodically, the Forest Service assesses production and consumption of a single timber product to determine its importance to the entire timber industry of a region. A 1984 canvass of veneer manufacturers in the Northeast showed that veneer manufacturing ranks third in the region in terms of wood received at primary wood-processing mills.

Earlier assessments of veneer production and consumption have been conducted in the area, beginning in 1963. During the latest period, between 1980 and 1984, total veneer-log production increased by 19 percent, rising to over 187 million board feet by 1984. Receipts at northeastern veneer mills, the consumption of veneer logs, rose 28 percent, to approximately 154 million board feet. These increases occurred even though the number of veneer mills declined by five in the Northeast between 1980 and 1984.

Northeastern timber harvesters continue to supply high-quality veneer logs to mills located in the region and elsewhere. Since 1963, regional exports have exceeded imports. Declining in the mid-1970's, the net export of veneer logs has subsequently increased, reaching approximately 26 million board feet by 1984, a 14-percent surplus.



Sharp increases in the production and receipts of veneer logs at mills characterize the last decade.

Foresters and loggers know that not all timberland is created equal--some is more easily managed or logged than other land, and some, perhaps, should not presently be managed or logged at all. "Operability" is the word used to define this relative ease or difficulty of managing or harvesting timber because of physical conditions in the stand or on the site. If land managers or timber-procurement personnel could rate timberland for operability, it would help them to screen out marginal management or harvest opportunities and to give priorities to the remaining ones.

Scientists at the North Central Station developed a method for evaluating the operability of timberland using information routinely collected during Statewide forest inventories by Forest Inventory and Analysis field crews. The technique uses seven items computed from data collected on permanent sample plots, such as stand area, volume per acre, and percent of cull trees in the stand. The method allows the user to ignore up to three of the seven operability components deemed unimportant to him. It also permits the user to determine the area of timberland and the volume of timber by operability class and by its distance from wood-using centers in a State.

Aerial photography helps foresters determine the operability of timber stands before they make harvesting decisions.

Forest Service inventory and analysis foresters tally sample trees the way salesclerks inventory groceries. The use of data recorders for forest inventory work in the United States was pioneered by the Forest Inventory and Analysis (FIA) unit at the Southern Station in 1978. Subsequently, an evaluation of portable data recorders by the Pacific Northwest Station and the implementation of a Servicewide computer network provided the impetus for other FIA units thoughout the country to field test these recorders.

We are finding that young inventory field foresters, who are familiar with video games and personal computers, prefer using data recorders over traditional plot tally sheets. The software programs necessary for data transmission and entry are being developed jointly by several experiment stations. Telecommunications and data capture and subsequent processing are reliable and efficient. Keypunching costs, time requirements, and the associated errors of handling the data at several stages of entry are eliminated. Our experience in manipulating FIA data demonstrates that new technology is not always conceived from "Star Wars" types of research and development.

We found that younger field workers are most comfortable using handheld calculators and other electronic devices for transmitting forest inventory data.

The Forest Inventory and Analysis program provides continuing information about the Nation's changing forest and rangeland resources. Forest industry, financial consultants, and State resource planners who depend upon this inventory data, need updated statistics in order to monitor the effectness of their activities. New statistical publications were issued this year for California, Illinois, Louisiana, Montana, Nebraska, New Hampshire, Vermont, Virginia, and Wisconsin. These reports describe the volume and species of timber, its quality, the condition of the forest understory, and other variables, for the forest resource in each State. In addition, reports of special studies dealing with timber production, attitudes of forest owners, and the application of improved technology to forest inventories were published.

The implementation of Forest plans involves decisions regarding when, where, and how to harvest timber, as well as when, where, and to what standard to construct timber-access roads. Such decisions can considerably affect both economic efficiency and the environment. Many resource managers believe that area-level analysis (ALA), an interdisciplinary process concerned with the management of contiguous land areas from 5,000 to 50,000 acres, is the logical next step once the information from a Forest plan is extracted in as much detail as is practical. Numerous approaches for ALA are possible, ranging from straightforward simulation to optimization techniques. Economists at the Intermountain Station have tested four analytical approaches to measure efficiency differences across the continuum from simulation to optimization.

1. **Fixed-Access Simulation (FX).** Managers decide how each potential harvest unit is to be accessed and fix this information in the simulation model. They then decide which units to harvest for each alternative developed (access routes are fixed in the analysis).

2. **Variable-Access Simulation (VR).** Managers choose which units to harvest and how to access those units for each alternative developed (access routes can be changed in the analysis).

3. **Simulation With Minimization of Road Costs (MC).** Managers select the units to harvest and then use an optimization routine to determine the least costly transportation plan for accessing those units.

4. **Optimization (MX).** A model selects the harvest and road construction activities that maximize or miniminize a specified objective function while satisfying other management objectives specified as constraints.

Each approach was tested twice on three actual planning areas, using the same data and management objectives within each area over the 50-year planning horizon. Forest Service managers selected the harvesting and road construction projects in the simulation approaches. The discounted net timber revenues per acre for the MX approach were significantly higher than for the other approaches. From the results of this study, it appears that the MX approach has much potential for increasing cash-flow while achieving other management goals and objectives specified in Forest plans.

Ad valorem property taxes have long been criticized as a method of taxing forest properties because they impose an annual tax on both land and timber even though most forest properties do not provide annual income. In response to this criticism, several States have enacted optional yield tax laws, which attempt to encourage better forest management by deferring all timber taxes until timber is actually harvested. At present, 9 States have a total of 11 such statutes.

These laws were recently studied under the terms of a cooperative agreement involving economists from the Southern Station and North Carolina State University. Major objectives of the study were (1) to determine the extent to which each piece of legislation was being used, and (2) to identify what, if any, administrative problems were being encountered. The results indicated that only four of the programs--those of Massachusetts, Michigan, Missouri, and Wisconsin--had succeeded in attracting a substantial number of participants.

The principal reason for the generally low levels of landowner acceptance seemed to be (1) absence of an obvious tax advantage, (2) severe eligibility restrictions, (3) unawareness of all relevant tax options, (4) reluctance to relinquish control over certain management decisions, and (5) unwillingness to allow free public access to enrolled acreage. These findings were used by the investigators to formulate several recommendations for improving program effectiveness.

The owner of this 17-year-old pine plantation in Mississippi and his consulting forester have plenty to smile about. A pulpwood cut removed about 20 percent of the stems, providing interim income to the owner, and the remaining trees will bring top prices in a few more years. Tax treatment of standing timber greatly influences how much "management" the typical landowner can afford.

Forest economists at the North Central Station have developed a timber harvest scheduling model that provides a relatively inexpensive methodology for analyzing the consequences of alternative future scenarios of regional timber use. The model utilizes both dynamic programming and basic concepts of timber-production economics. A recent application of this model examined the impacts of the use of wood for energy on future timber supply in northeastern Minnesota. Specific attention was directed to the impact of wood energy use on the supply costs for other timber products users. Six scenarios of future use levels of conventional timber products and wood for energy were evaluated. The results indicated that with appropriate management actions, wood energy use could be increased significantly without raising the supply costs of other timber products.

To comply with the Renewable Resources Planning Act (RPA) of 1974, the Forest Service must inventory forest and rangeland resources and determine their economic value. It is relatively easy to assign a value to tangibles like timber or water, but some of our finest wildland assets, like outdoor recreation, cannot be measured easily. Three Rocky Mountain Station economists have been working on this problem.

"Toward an Improved Framework for Estimating RPA Values," by George L. Peterson, Thomas C. Brown, and Donald H. Rosenthal, identifies and separates the important issues and provides new concepts and guidelines for assigning economic values to the varied products and uses of our Nation's forest and rangeland resources. One of the most important of several contributions is identification of subaccounts by which to estimate economic values. These subaccounts represent different objectives that may be of concern to different interest groups affected by forest planning. The results of this research will be used in the development of the 1989 RPA program.

The profitability of investments in forest land and forest management depend not only on the prices received for timber harvested but also on the costs of forest management. Economists at the Southern Station analyzed trends in harvesting and regeneration costs from 1979 to 1984 and found that the cost trends differ depending on the management activity.

Harvesting costs have kept pace with inflation, except for marking and whole-tree chipping. Marking costs increased 50 percent faster than inflation, primarily because labor costs have increased faster than labor productivity. Chipping costs have increased at twice the rate of inflation. Downward trends in fuel prices during 1985-86 are a two-edged sword, reducing the cost of chipping but also reducing the chips' value as an energy source. Though chipping can help reduce the cost of site preparation by removing harvest residues and residual vegetation, such benefits may not offset the reduction in fuel value of the chips produced.

Site-preparation costs have also kept pace with inflation, primarily because managers have shifted to less-intensive preparation practices to hold down cost increases. The result is that harvest residues are not broken down as effectively, and more vegetation remains to compete with seedlings for light, water, and nutrients. Consequently, broadcast burning costs have risen faster than inflation.

The cost of planting seedlings by machine has kept pace with inflation. But the acreage planted by machine has declined because rougher sites remain after less-intensive site preparation. In the South, 70 percent of planting is now done by hand. This process--25 percent less expensive today than in 1979--is now less expensive than machine planting.

Analysis of the cost trends shows that controlling competing vegetation is the driving force behind shifts in practices and costs. If not controlled prior to harvest, unmerchantable trees and brush respond to a harvest operation by moving quickly to dominate the site. Controlling competing vegetation before harvest not only reduces regeneration costs and improves regeneration success but also pays harvesting dividends by increasing stumpage prices and reducing marking costs. Harvesting and regeneration operations must be integrated to secure the most economic benefits.

This field crew is planting pine seedlings by hand, to regenerate an old burned area on the Francis Marion National Forest in South Carolina. Changes in labor costs have made hand-planting cheaper than machine-planting in the late 1980's.

The South's forest-products industry experienced significant growth during the 1970's. How this change affected employment, earnings, and productivity is the subject of a series of analyses by Forest Service and cooperating university economists for each of the 13 Southern States.

Between 1970 and 1980, most of the States increased their share of the Nation's employment and earnings in the forest-products industry. North Carolina, for example, had nearly 20,000 more employees in 1980 than it would have had if its forest-products industry had grown at the national rate; its earnings were nearly a quarter of a billion dollars more than otherwise. Arkansas and Louisiana were exceptions--they both had a smaller share of employment in 1980 than in 1970.

The forest-products industry is a significant component of the economic base of most Southern States (the economic base is comprised of industries producing for export outside the State). In 1980, for example, the forest-products industry accounted for one out of six basic employees in Arkansas, North Carolina, and Mississippi.

Increases in productivity exceeded increases in payroll per worker between 1972 and 1977 for all Southern States, a fact that is responsible in part for the South's comparative advantage in the forest-products industry. The average productivity for all manufacturing industries exceeded that of the forest-products industries in 11 of 13 Southern States. But the forest-products industries in five States--Alabama, Georgia, Louisiana, Oklahoma and South Carolina--exceeded the industry's average for the Nation.

Slash pine plantations like this one near St. Matthews, SC, keep the South's timber industry humming. Forest products account for a tremendous share of the region's contribution to the gross national product.

Area changes for land uses are important considerations in analyzing prospective supplies of natural resources such as timber, wildlife, and forage. In the South, timberland occupies approximately three-fifths of the land base and is chiefly in private ownership. This proportion has been dropping since the early 1960's as agriculture and developed uses expanded. Researchers at the Southeastern Station analyzed data pertaining to land use and associated determinants of private-area change dating back to the 1940's to find out how and why the region's timberland base is changing.

Econometric analysis of the data revealed that changes in the acreage of timberland in private ownerships occur due, largely, to forces outside the forestry sector, primarily changes in population and personal income. Our economists used estimated relationships between land-use areas and variables such as population, personal income, and income from agriculture and forestry to develop models of area change for the South.

With these models, we projected area changes for 12 Southern States in an ongoing study of the timber supply situation in the South. Projections indicate that timberland area will continue to drop in the South, in large part due to continued conversion of timberland to urban and developed uses. The projected timberland area reduction is primarily on farm ownerships.

For the Renewable Resources Planning Act and other planning processes, the Forest Service needs better means to evaluate the benefits of timber utilization research. A recent study done at the University of Minnesota in cooperation with our Forest Products Laboratory analyzed the benefits of forest-products research by determining its impact on softwood timber utilization. Selected improvements in seven groups of technologies were analyzed, including lumber production and use, and the production of panel products and pulp and paper. The cost of research to develop the improvements in the 1970's was compared to expected discounted net savings of softwood timber through the year 2000.

Results indicate that expenditures on timber utilization research in the 1970's have been well justified. In fact, the benefits from the seven technologies analyzed justify the expenditure for all timber utilization and timber management research done in the 1970's by public and private laboratories. The expected benefits from the selected utilization improvements consitute an estimated 18-percent rate of return on 1970's timber utilization and timber utilization research through the year 2000.

Forest Products Laboratory employees load a section of veneer log onto the lathe that will peel off the veneer. Ongoing experiments deal with increasing the amount of usable material from trees via improved logging and machining techniques.

In managing forest resources for multiple uses, joint outputs from the same tract of land or ecosystem occur frequently. A vexing problem for managers of public forest lands is allocation of costs to separate products or values in situations where the management inputs occur as nonseparable costs. Economists at the Rocky Mountain Station conducted a rigorous theoretical and empirical investigation into the nature of a managed forest ecosystem as a multiple-use production unit. The theoretical work concludes that if production processes--for example, timber and wildlife--are interrelated, then joint cost-allocation problems can occur. The empirical work analyzed a particular forest area and tested this hypothesis. Management treatment costs were appraised as single output costs and then appraised as portions of joint costs. The actual errors encountered in costing outputs individually vary from 8 percent to 60 percent of the actual joint cost.

The policy implications of these findings are simple: if attempts are made to cost forest and range outputs independently, the sum of output costs may be less than the true cost of producing the set of outputs. Thus, if decisions are made concerning the level of different outputs based on individual output costs, misallocation of resources may result. This research is currently being applied in developing the 1989 RPA Assessment.

America's national forests provided unparalleled recreation opportunities. Here in the Mammoth Lakes Recreation Area on the Inyo National Forest, in California, a fisherman and a group of riders make use of the State's natural beauty. Part of the Forest Service's job is to evaluate the tradeoffs in restricting timber harvesting to maintain recreation areas such as this.

Taxes, their relationship to forest land ownership, and their implications for forest-management decisionmaking have been a matter of great interest in United States forestry circles for more than a half century. In 1923, for example, a U.S. Senate select committee on reforestation ranked taxes as the second most serious obstacle to private forestry, behind forest fires. Congress passed the Clarke-McNary Act the following year.

One section of the act called for a nationwide study of forest taxation. The study's major report, entitled "Forest Taxation in the United States," was published in 1935. It was a monumental and comprehensive work and is still a basic forest tax reference.

Today the influence of taxes on forest management is as lively a subject as it was in the 1930's. Many forest economists rank taxation as the most influential factor in determining the viability of a forestry investment. The impact of taxes is a dynamic process--tax laws are constantly changing, new tax legislation of some type is always being enacted, and new judicial interpretations of existing law are continually being rendered.

Many State and Federal taxes currently pose serious obstacles to forest investment. At the same time, however, many offer overlooked economic opportunities. In recent years the Forest Service has responded to this changing tax environment by conducting a comprehensive, continuing forestry tax research program centered at the Southern Forest Experiment Station. Examples of recent research include (1) development of guidelines for forest landowners to determine the best way to recover silvicultural costs on their Federal income tax; (2) analyses of court decisions on interpretations of landowner's eligibility to claim long-term capital gain on timber sales; and (3) analyses of the features of 11 existing optional State forest yield-tax laws, including owner eligibilty, procedures, and apparent success. The results of these and other forest taxation studies are presented in Station papers, journal articles, and other published materials.

Researchers at the Intermountain Station in Missoula, MT, have been conducting studies to identify and evaluate both the nature and magnitude of timber harvest costs borne for multiple goals and nontimber outputs. Three lines of research are being pursued. First, researchers are measuring the costs of mitigation and enhancement activities undertaken on behalf of nontimber objectives during timber harvests in the Northern and Intermountain Regions. Costs include agency-incurred sale preparation and administration costs as well as reductions in stumpage receipts resulting from operator-incurred costs. This research builds on recently completed research that estimated an average cost of $26 per thousand board feet for nontimber provisions in Northern Region timber sales. A second line of research is developing the technology needed for planning groups of timber sales within a subarea of a national forest.

Research results indicate that potential cost savings from the systematic integration of timber harvest and transportation development activities are enormous. Research has focused on comparing the relative efficiency and effectiveness of different analytical approaches to this integration. Current research is streamlining analytical procedures and making them easier to use.

Finally, researchers are involved with studies pertaining to apportionment of joint costs in timber sales--costs incurred in the simultaneous and unavoidable production of multiple products. This research is designed to assess the opportunities, options, and problems for apportioning timber-sale costs to the products and objective served.

Results of this research program are available in Intermountain Research Station papers INT-361 on timber sale planning and INT-351, along with an article appearing in the June 1986 issue of American Forests on timber-sale costs. Other results are currently being prepared for Station and journal publication.

Improving Sediment Yield Estimates From Forest Roads

Controlling erosion from forest roads is hampered by our limited ability to estimate sediment yield from these roads and to evaluate the effectiveness of erosion-control treatments. Studies at the Intermountain Station address the problems of (1) developing better ways to predict sediment yield and, concurrently, (2) evaluating the cost-effectiveness of various erosion-control treatments for forest roads.

Our scientists have developed sediment yield information for a wide range of road standards, road gradients, and geologic materials. Two basic methods of determining rates of surface erosion are being used: (1) simulated rainfall applied to selected road sections to establish relative differences in sediment yield for roads built in different geologic formations or built to different gradients or standards, and (2) instrumented road sections established to provide actual long-term differences in sediment yield between different roads under conditions of natural rainfall and snowmelt. The two methods are complementary. Simulated rainfall allows us to obtain directly comparable sediment yield information for road sections subjected to a common "design storm" of known magnitude and energy. Instrumented road sections provide a way to measure the effects of natural storms over a longer period of time.

We found wide variability among geologic materials in erodibility and rate of sediment production. The effectiveness of erosion-control treatments in reducing sediment generation and movement also varies. Some of the more cost-effective treatments are gravel surfacing, vegetative or mulch cover on cut-and-fill slopes, and filter windrows of slash at the base of fill slopes.

Our information has been incorporated into computer models that significantly improve our ability to predict sediment yields from either existing or proposed roads and help specify the most cost-effective road design, construction, and treatment practices to reduce erosion. The sediment yield information can be used as part of a national effort directed by the USDA Agriculture Research Service for development of improved soil loss-prediction models.

To discover how rainfall affects sediment production from forest roads, we apply an artificial rainstorm of known intensity and duration to an instrumented section of road. Later, a technician will collect sediment samples for analysis.

A large timber base has been established by the extensive planting of southern pines in the South over the past three decades. In the next few years, many of these stands will require thinning to achieve the best economic return. A mixture of methods and equipment is currently being used for thinning, but managers need improved machines and systems to reduce costs.

Research engineers at the Southern Station have evaluated several mechanical thinning systems in terms of both production and cost. They evaluated functions such as grapple skidding, gate delimbing, flail delimbing, and felling with rubber-tired, swing feller-bunchers. Production and cost estimates were also developed for the individual functions and machines. This information can now be used for evaluating alternative thinning systems in southern pine plantations.

In support of the field studies, several new research tools have been developed. They include a hand-held calculator system for recording elemental time-study data, a pine plantation stand-plotting program, and an interactive microcomputer model for simulating feller-buncher operations. Actual, partial, or composite stands can be generated and plotted to evaluate alternative felling methods. The interactive simulation model coupled with the stand plots can be used to develop felling patterns and to determine the operating characteristics of various feller-bunchers.

This swing feller-buncher fells trees and bunches them up in clumps for easy removal during thinning operations in a southern pine plantation.

The chemical makeup of wood is basically that of a three-dimensional substance, composed primarily of the polymers cellulose, hemicellulose, and lignin. These polymers make up the wood cell walls and are responsible for most of wood's physical and chemical properties. Therefore, if the basic chemistry of the cell-wall polymers is changed, the basic properties of the wood will be changed.

Untreated wood swells when exposed to moisture because its cell-wall polymers attract water molecules and form chemical bonds with them. This bonding process is reversible: under lower moisture conditions, the water molecules are lost, and the wood shrinks. This lack of dimensional stability can be a serious problem when wood is used for such purposes as millwork, furniture, and cabinets because the movement during moisture gain or loss can distort the finished product. However, research has shown that the undesirable swelling and shrinking of wood can be reduced considerably, making it more stable, through the process of cell-wall modification.

Treating wood with acetic anhydride causes the cell-wall polymers to form acetyl bonds, making them incapable of attracting moisture molecules. The net effect of this treatment is greater dimensional stability.

Research chemists at the Forest Products Laboratory have successfully demonstrated that the problems inherent in the acetic anhydride treatment can be overcome by using a special dip procedure, followed by a period of heating. This new technique treats small flakes, particles, or fibers and results in their complete acetylation, which makes the treatment more cost effective. The treated material can be formed into panel or molded products that have greatly improved water resistance and dimensional stability. Research has shown that this acetylation process has little effect on the strength properties of the resulting wood material, and there is very little color change in the finished product.

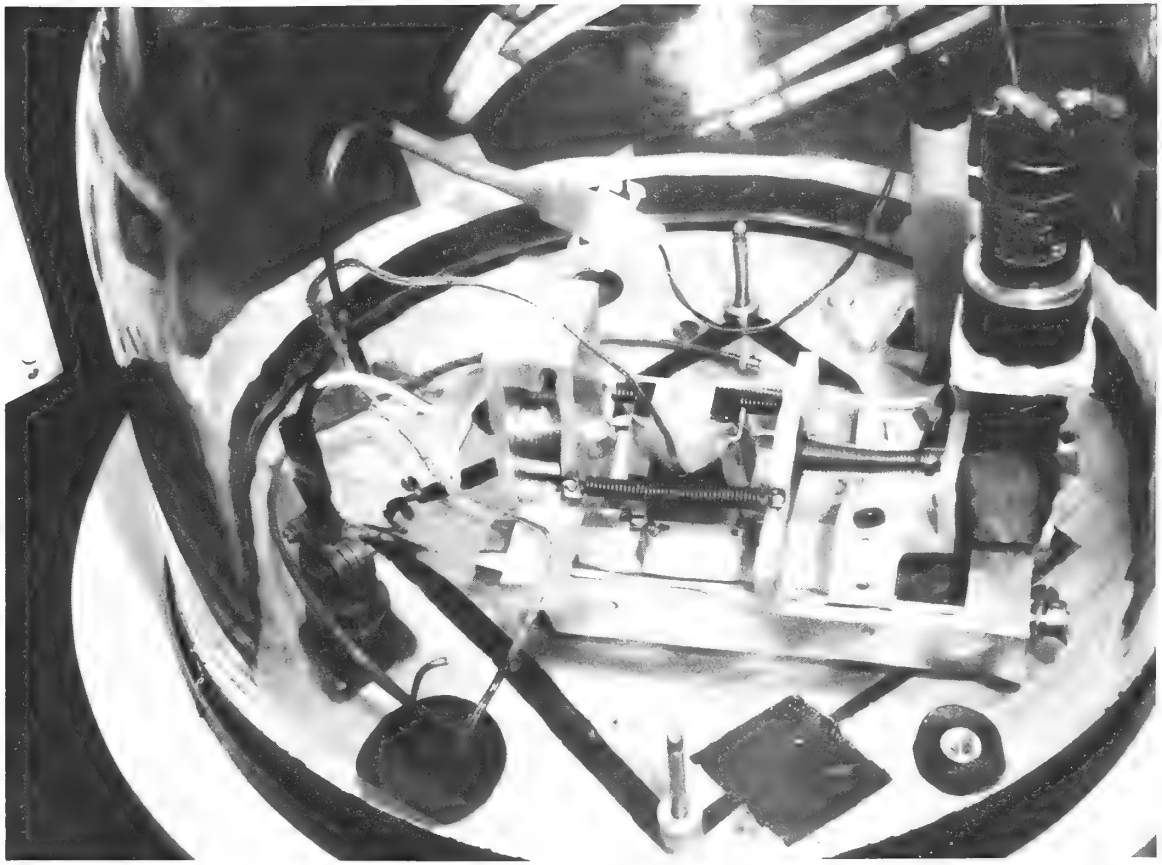
Chemical modification of wood at the Forest Products Laboratory has substantially increased its dimensional stability.

The mechanical response of paperboard to creep deformation, long-term loading, and cyclic changes in humidity is critical to its performance in structural applications. Yet in the past, industry has virtually ignored these effects because of the difficulty of performing controlled tests.

Researchers at the Forest Products Laboratory have developed a unique apparatus for investigating the performance of paperboard under changing conditions of humidity and edgewise compression. A vacuum restraint system holds the paperboard specimen in position for compressive testing, and specimen equilibration time is reduced from several hours to a few minutes. With this apparatus, it is possible more accurately and reliably to measure stiffness, compressive strength, and duration-of-load performance during creep tests in constant or changing humidity conditions.

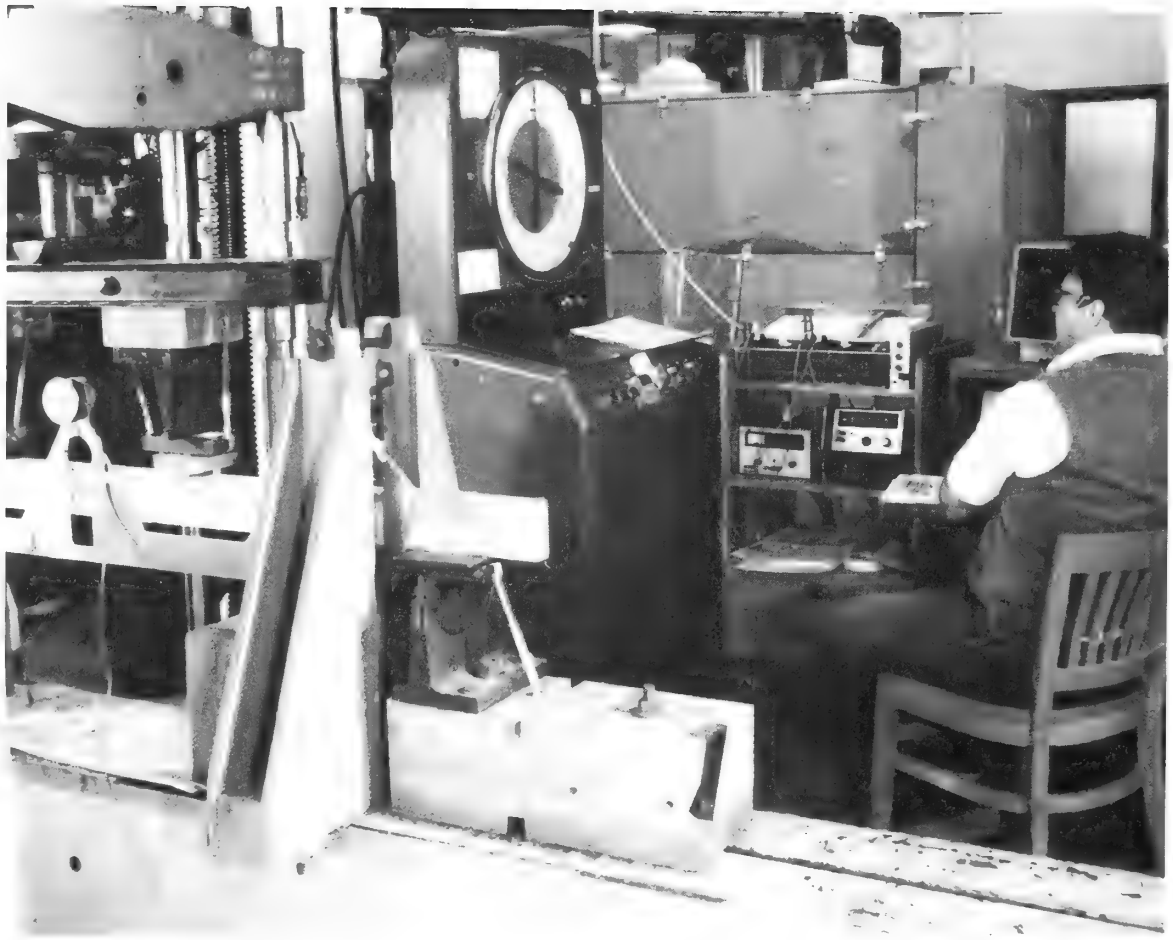
This versatile new apparatus makes possible a more complete analysis of paperboard properties in real-world conditions. This opens the door to true performance-based evaluation of structural paperboards, which will lead to improved design of corrugated containers and lower container cost.

This apparatus measures strength, stiffness, and deformation of paperboard at variable rates of load and humidity.



Recent research on the effect of moisture content on the mechanical properties of Douglas-fir and southern pine dimension lumber indicates that strength generally increases as lumber dries, but not as much as has been assumed in engineering design codes. This new research indicates that low-quality lumber (for example, No. 3 grade) would not increase in strength as it dries. The strength of high-grade lumber (such as Select Structural) would increase 40 percent in drying from green to 12-percent moisture content. Our researchers have developed analytical models that can be used to predict changes in lumber strength as a function of a change in moisture content. These models are applicable to all grades and all widths of dimension lumber and to all strength levels within a grade.

The new analytical models are currently being used to adjust data being collected in both the U.S. and Canadian "In-Grade" testing programs. The models will form the basis for new adjustment procedures in engineering design codes in both countries. These models allow more accurate design of timber structures by architects and engineers.



A Forest Products Laboratory procedure for adjusting flexural properties of dimension lumber will allow revisions in codes and standards.

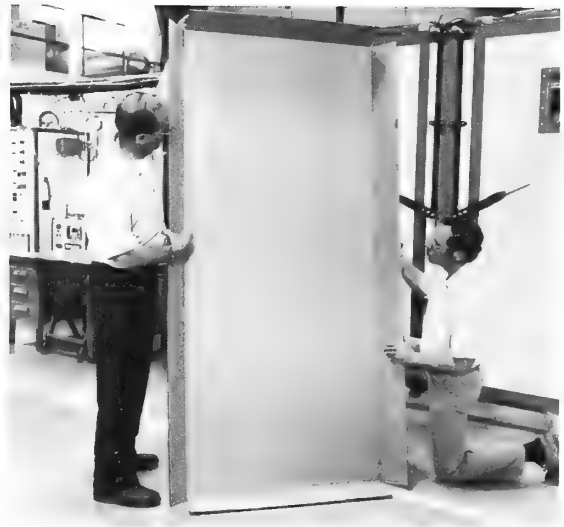
Integrating new construction methods in our conventional building system is particularly challenging. Light-frame construction methods have been based on traditional methods, which do not relate directly to performance requirements or capabilities. Construction designed to meet performance standards is usually cheaper than that based on convention and tradition. Considerable progress has been made to design low-cost housing that is energy efficient, structurally sound, and has long-term durability. Advances in mechanical fasteners, semirigid adhesives, engineered structural components, and structural analysis techniques have enabled the housing industry to use products compatible with the changing raw material supply in an efficient way. One such example is the truss-framed system for housing which integrates roof truss, floor truss, and wall studs into unitized frames. Public patent No. 4,005,556 is available to anyone who desires to make use of it. Several thousand truss framed houses have been built to date.

Using the Truss-Frame System, a small crew of laborers can frame up an average house in just a few hours.

Much of the 60 million tons of wood pulp produced annually in the United States is converted into paper and paperboard material to protect products ranging from fresh vegetables to computers. Because the strength of paper and paperboard diminishes rapidly when they are exposed to high humidity and moisture, it is critical to improve and maintain paper strength under these adverse conditions. SOFORM--a new process developed by scientists at the Forest Products Laboratory--solves this problem.

SOFORM is a chemical treatment that imparts wet stiffness (stiffness after long-term soaking) to paper and paperboard. It involves formaldehyde crosslinking using sulfur dioxide as a catalyst. These linkages lock the cellulose molecules together, which prevents swelling and loss of strength and stiffness. Studies have shown the process can improve paper's dimensional stability by about 80 percent and maintain wet stiffness almost equivalent to its dry stiffness.

If material the size of conventional wall panels can be made insensitive to moisture, paperboard products will become suitable for a wide range of engineered structural uses. Some of the potential uses for SOFORM-processed fiberboard materials are emergency shelters for disaster victims, wall and ceiling panels, and other related building applications.



Double-wall fiberboard, crosslinked in the Forest Product Laboratory's SOFORM process, may be used in engineered structural operations.

Past work at the Forest Product Laboratory's Institute for Microbial and Biochemical Technology resulted in the discovery of ligninase, the first described enzyme to degrade lignin (the material in cell walls of wood that accounts for its stiffness). This enzyme is secreted by a fungus that causes white-rot decay in wood. During degradation, the enzyme causes oxygen from the air to be combined with lignin, resulting in breakdown of the lignin.

Further research has shown that the fungus and its isolated ligninase also oxidize certain environmental pollutants, including polycyclic aromatic hydrocarbons and chlorinated dioxins. This ability to degrade pollutants evidently parallels the enzyme's capacity to degrade lignin because the molecular structure of many of these pollutants resembles that of lignin.

Because the enzyme and the fungus degrade aromatic pollutants, they have been proposed as agents for biological waste treatment. We believe that the lignin-degrading system of wood-rotting fungi could play a significant role in the detoxification of human-caused pollutants.

Forest Products Laboratory research shows that the enzyme ligninase oxidizes certain human-caused environmental pollutants. We are hopeful that ligninase will have applications in detoxifying pollutants whose chemical structure resembles that of lignin, the natural cell-wall polymer in wood.

Good forest management often dictates the removal of small and cull trees, but managers will not implement such cuttings unless a profitable market exists for this material. Also, forest residues (such as limbs and branches of merchantable trees left in the forest) and mill wastes (such as sawdust, planer shavings, slabs, and edgings) are often wasted fiber or become serious disposal problems. But such material can be turned into valuable products when utilized for the production of flakeboard, particle board, and oriented strand board.

Research published by the Forest Products Laboratory explains how to produce composite panels from low-value trees and residues. Several publications have been instrumental in sucessfully transfering this new technology to user groups.

We know this research is valuable because existing mills accepted it readily, and new plants are being built in New England, the East, the South, and the Rocky Mountain area. These new plants alone have created hundreds of new jobs, mostly in rural communities, and the increased production of composite panels is helping to strengthen our Nation's economy.

Particleboard made by the Forest Products Laboratory's steam injection pressing process may incorporate furnish from low-value trees and residues. The development of economical uses for such waste products will encourage managers to clear debris out of their woods, decreasing fire danger at the same time by reducing fuels on the forest floor.

There are several million acres of small-diameter, stagnated stands of lodgepole pine in the West. These forests are growing very slowly and present a significant management challenge across much of the region. Besides being an underutilized wood and fiber resource, such stands occupy lands upon which effective multiresource management for watershed, wildlife, recreation and other uses is critical.

A recently completed 5-year effort has evaluated harvesting, utilization, and silvicultural alternatives in small-diameter lodgepole pine stands. Studies included testing harvesting systems and techniques under both clearcut and partial cut silvicultural prescriptions, developing information on tree and stand characteristics as part of products and processing research, evaluating product recovery and value opportunities, evaluating biological and nontimber resource response to stand treatment, and estimating longer term economic and management consequences of harvesting in these stands.

The collective results of this research provide a basis from which managers can select the alternative management and utilization practices for small-diameter lodgepole pine stands. Results have been documented in various publications that are available from the Intermountain Forest and Range Experiment Station in Ogden, UT.

A small trailer-mounted cable yarder is an economical and efficient way to recover small timber from steep slopes. Managers who can make some financial recovery from small-stem lodgepole pine stands through an intermediate harvest are more likely to practice thinning, which helps protect stands from insect pests like the mountain pine beetle.

The results of more than 60 years of continuing Forest Products Laboratory research on exterior wood finishing are brought together in the 56-page Agriculture Handbook No. 647, entitled "Finishing Wood Exteriors: Selection, Application, and Maintenance."

This practical handbook will be a useful guide for do-it-yourself homeowners, and serve as a valuable reference work for professional builders, architects, and wood finishers. It begins with the basic characteristics of wood and reconstituted wood-based products, focusing on their finishing and performance characteristics, manufacturing and construction practices that affect surfaces to be finished, and the ways that various finishes interact with these characteristics. The handbook provides detailed information on various types of exterior wood finishes, together with the proper application procedures for each. Principal subjects include paints, solid-color stains, semitransparent penetrating stains, transparent coatings, and water-repellent preservatives. Other topics of interest include the weathering of wood, treated wood products, fire retardants, and moisture-excluding finishes. Special applications and treatments needed for wood decks and porches, fences, roofs, log structures, and marine environments are outlined in several sections. Steps are also given for diagnosing and correcting finish failures on wood surfaces.

Copies of Agriculture Handbook No. 647 are available from the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Stock number: 001-000-044-50-8. Or from the Consumer Information Center, Department 137R Pueblo, CO 81009. Price: $3.25.

Sixty years of continuing research by scientists at the Forest Products Laboratory is summarized for homeowners in "Finishing Wood Exteriors."

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